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Geotechnical and Structures Laboratory

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Airfield Damage Repair Modernization Program

Validation of FRP Matting Requirements

John F. Rushing, Webster C. Floyd, Timothy W. Rushing, Lyan Garcia, William D. Carruth, Jeb S. Tingle, and Craig A. Rutland

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Abstract

The U.S. Army Engineer Research and Development Center executed a field demonstration for the Air Force Civil Engineer Center to validate requirements for using Fiber Reinforced Polymer (FRP) matting as a foreign object debris cover when repairing damaged airfield pavements using crushed stone. A side-by-side comparison between FRP and folded fiberglass matting (FFM) was performed on simulated small, medium, and large craters in Portland cement concrete and asphalt concrete pavements. The demonstration took place at the Silver Flag Exercise Site at Tyndall AFB, Florida. Experienced non-commissioned officers from multiple units performed the crater repairs and matting installations. Tools, processes, and team requirements were evaluated during the demonstration. Results from the demonstration indicate that FRP matting can be installed faster than FFM, and simulated traffic tests proved that FRP can meet the minimum traffic requirements.

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Preface

This study was conducted for the U.S. Air Force Civil Engineer Center (AFCEC). Technical oversight was provided by Jeb S. Tingle.

The work was performed by the Airfields and Pavements Branch (GMA) of the Engineering Systems and Materials Division (GM), U.S. Army Engineer Research and Development Center, Geotechnical and Structures Laboratory (ERDC-GSL). At the time of publication, Dr. Timothy W. Rushing was Chief, CEERD-GMA; Dr. Gordon W. McMahon was Chief, CEERD-GM; and Nicholas Boone, CEERD-GZT was the Technical Director for Force Projection and Maneuver Support. The Deputy Director of ERDC-GSL was Dr. William P. Grogan, and the Director was Bartley P. Durst.

COL Bryan S. Green was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
feet	0.3048	meters
inches	0.0254	meters
kip-inches	112.948	newton-meters
pounds (force)	4.448222	newtons
pounds (force) per square foot	47.88026	pascals
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters

1 Introduction

1.1 Background

For decades, folded fiberglass mat (FFM) has been the U.S. Air Force solution as a foreign object debris (FOD) cover for repairs over crushed stone backfilled craters. Its design provided adequate support for airframes operating during that time. In 2005, a test conducted at the U.S. Air Force (USAF) Plant 42 Facility in Palmdale, California, revealed that FFM matting was not strong enough to withstand traffic from C-17 aircraft. These aircraft had not been used for testing with FFM since their incorporation into the USAF fleet in the 1990s. An alternative FOD cover matting solution, Fiber Reinforced Polymer (FRP), was identified as a potential replacement as the USAF airfield damage repair (ADR) matting solution. During the same experiment, the legacy FRP matting system was also incapable of supporting traffic loads induced by modern cargo and fighter aircraft. Failures in the legacy FRP occurred solely in the connecting and anchor bushings themselves. However, the FRP mat panels remained undamaged. A new modified FRP system with redesigned connector and anchor bushings was then developed. This new system was live-flight certified in 2009 for fighter and cargo aircraft (Priddy et al. 2011).

1.2 Objective and scope

The objective of this experiment was to optimize procedural guidance for installing FRP matting and to develop an inventory of supplies to be included in a supporting toolkit. The demonstration was conducted at the Silver Flag Exercise Site at Tyndall Air Force Base (AFB), Florida, from 20 August 2015 to 09 September 2015. During the period 24 August 2015 to 03 September 2015, 16 Rapid Engineer Deployable Heavy Operational Repair Squadron Engineer (RED HORSE) airmen, ranking from Senior Airman through Master Sergeant and from multiple squadrons were trained on the new technologies and executed simulated crater repairs on the training runway. Half the group was used to prepare the craters for the matting installation, and the other half was used to assemble and install matting.

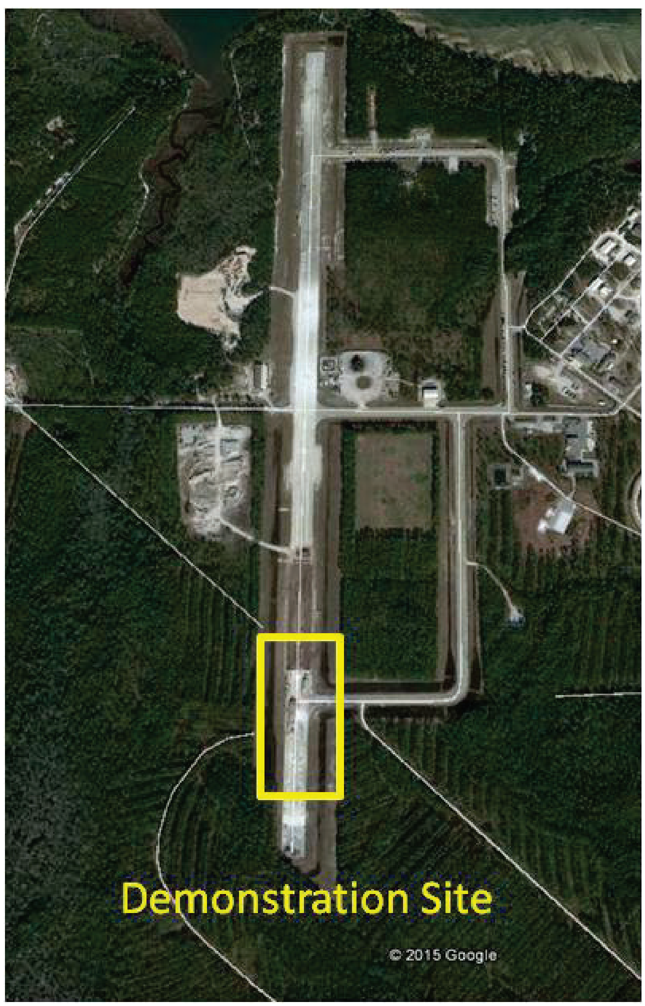
Three simulated craters defined as *small*, *medium*, and *large* were created in the existing Portland cement concrete (PCC) runway and repaired with both FFM and FRP matting. In addition, *small* and *large* craters were simulated on the asphalt concrete (AC) taxiway, and repair assemblies for each matting system were installed. Timing data to perform each task associated with the repair process were recorded. Simulated traffic was applied to the runway repairs to ensure the matting systems could withstand the required 100 passes of mixed traffic.

2 Description of Field Demonstration

2.1 Test site

The work described in this document was performed on the south end of the PCC runway of the Silver Flag Exercise Site, Tyndall AFB, Florida, as indicated in Figure 1. This area has been frequently used for demonstrating crater repair technologies. Therefore, many of the pavement slabs were previously disturbed. Locations within the test area were identified that would allow for performing the necessary repairs with ample room to apply simulated traffic.

Figure 1. Aerial view of demonstration site.



2.2 Personnel

Sixteen RED HORSE airmen from various units participated in the demonstration. Eight of the airmen were heavy-equipment operators and eight were structures specialists. The equipment operators were responsible for sawing, demolition, excavation, and backfill of the craters. The structures personnel were responsible for assembling and installing FOD covers over the crater repairs.

2.3 Training

Both classroom and field training were used to prepare the airmen for the demonstration exercise. During classroom training (Figure 2), the airmen were provided detailed descriptions of the products and technologies as well as the procedures that would be used during the demonstration. Once classroom training was completed, the airmen practiced the actual demonstration steps using all of the equipment and tools that comprised the FRP ADR package. Training continued until each group was proficient at all the ADR processes that would be timed during the demonstration. Actual timeframe (days per activity) is important in understanding the training requirement.

Figure 2. Classroom training.

2.4 Materials

The crushed limestone backfill used in crater repairs was provided by the Vulcan Materials Company from their local Panama City plant. Table 1 provides the gradation of the crushed limestone backfill material. The material is generally well graded with 98.4% passing a standard ¾-in. sieve. The bulk specific gravity of the coarse aggregate portion of the crushed limestone material was 2.75 with a reported 0.3% absorption rate. The fine aggregate portion of the crushed limestone material had a bulk specific gravity of 2.67 with a reported 1.0% absorption rate.

Table 1. Crushed limestone backfill gradation.

Sieve Size	Percent Passing (%)
1 in.	100
¾ in.	98.4
½ in.	66.5
3/8 in.	55.0
#4	47.2
#8	28.5
#30	13.6
#50	10.7
#100	9.2
#200	7.9
Pan	0

2.5 Equipment and tools

For all crater demolition and backfill procedures, the equipment fleet represented the modernized ADR package. Once the crater repairs were completed, the legacy FFM matting system and the new FRP kit were used with their standard components. The following provides descriptions of the equipment and tools used during this experiment.

2.5.1 Modernized ADR equipment

2.5.1.1 Caterpillar 279D compact terrain loader (CTL)

Caterpillar 279D rubber-tracked compact terrain loaders (CTLs), also known as skid steers, were used during the demonstration. The CTLs had high-flow hydraulic systems capable of operating the ADR attachments. A Caterpillar SW45 wheel-saw attachment (Figure 3) and a 78-in. bucket attachment (Figure 4) were the primary tools used in the crater repair process. Wheel saws were used to rapidly cut the pavement surrounding the crater for a square-shaped repair. The bucket attachment was used for debris removal during the excavation process.

Figure 3. CTL with wheel-saw attachment.

Figure 4. CTL with bucket attachment.

2.5.1.2 Volvo EW180D excavator

Two Volvo EW180D wheeled excavators were used as part of the crater repair process. One was equipped with a HB1400 chisel-tipped hammer attachment (Figure 5) and was used to break PCC from within the repair area. The other was equipped with a 36-in.-wide toothed bucket (Figure 6) and was used for removing broken PCC and underlying material.

Figure 5. Wheeled excavator with breaker attachment.

Figure 6. Wheeled excavator with bucket attachment.

2.5.1.3 Caterpillar 926M front-end loader

A Caterpillar 926M front-end loader was used to load and transport crushed stone for the crater backfill (Figure 7). For the larger craters, stone was loaded into dump trucks that backed near the crater and dumped the crushed stone directly into the crater. For small craters, the front-end loaders were used to transport the stone for placement in the crater.

Figure 7. Front-end loader.

2.5.1.4 Caterpillar fork lift

A Caterpillar TL1055C extendable-boom fork lift was used to transport the matting systems (Figure 8). Additionally, a Caterpillar 10E913 forklift was borrowed from Silver Flag to assist with handling FFM matting. This forklift was used in training of the legacy system by Silver Flag. The two forklifts were used side by side for loading and unloading FFM. For FRP matting, the TL1055C was used to load/unload mats and to support the matting assembly as pieces were being unloaded during assembly.

Figure 8. Extendable-boom fork lift.

2.5.2 FRP matting kit

The complete FRP air-droppable mat kit, shown in Figure 9, was designed to be a scalable system that can support multiple crater dimensions and shapes. The kit was comprised of three main components, i.e., the prototype FRP mat container with FRP mat panels (contents in Table 2), a container with consumable materials (contents in Table 3), and a container with installation tools (contents in Table 4). The kit was designed so a single installation tool set could support multiple mat and consumable packages. The consumables and installation tools are packaged in two Hardigg 16848-100 Air Drop Boxes. The FRP panels were packaged in a prototype FRP mat container designed to function as a palletized skid that can be attached to a 20-ft, Type V airdrop platform. The two Hardigg 16848-100 Air Drop Boxes together with the prototype FRP mat container form a single air droppable kit. Each kit is capable of providing a FOD cover for 13 5-ft-diameter craters, five 10-ft-diameter craters, three 15-ft-diameter craters, or one large crater up to 28-ft diameter.

The remainder of this section provides a comprehensive listing of each component of the kit. For more information concerning the development and contents of the air-droppable FRP mat kit, see Rushing et al. (in preparation.)

Figure 9. Complete FRP air-droppable mat kit.

Table 2. FRP Mat Package item list – mat panels and bushings.

FRP MAT PACKAGE ITEM LIST		
Item No.	Item Description	Qty.
1	FRP Special Mat Container	1
2	Full-size panel w/lower bushings	7
3	Half-size panel w/lower bushings	6
4	Full-size Anchor Panel	3
5	Half Anchor Panel	4
6	M6A1 Ammo Boxes	12
7	Anchor Bolt Bushings (25 ea. in 5 ammo boxes)	125
8	Upper Connector Bushings (25 ea. in 7 ammo boxes)	175

Table 3. FRP Anchor Package item list – consumable materials.

FRP ANCHOR PACKAGE ITEM LIST		
Item No.	Item Description	Qty.
1	Hardigg 16848-100 Air Drop Box	1
2	Tri-Talon Anchor Assembly	120
3	Tri-Talon Set Tool	2
4	Rapid Set Mortar Mix, 50-lb bucket	20
5	Concrete Anchor Bolts, Power Bolt, 3/4 in. x 8-1/4 in.	120
6	Measuring Buckets, 2-qt capacity	4
7	Empty Buckets, 5-gal capacity	4
8	Shop towels to wipe rapid set off bolts (rolls/packs)	3

Table 4. FRP Installation Tool Package item list – installation tools.

FRP INSTALLATION TOOL PACKAGE ITEM LIST		
Item No.	Item Description	Qty.
1	Hardigg 16848-100 Air Drop Box	1
2	Hydraulic Power Pack	1
3	Hydraulic Hammer Drill	1
4	Hydraulic Earth Auger	1
5	2-in. x 42-in. Shaft-Flighted Earth Auger	4
6	Hydraulic Hose Set w/ couplers, 25 ft	2
7	Generator, Diesel, 5500W	1
8	Extension Cords, 50 ft	3
9	Reciprocating Saw	1
10	Reciprocating Saw Blades - metal (24 TPI)	25
11	Reciprocating Saw Blades - All purpose (14 TPI)	25

Table 4. (continued)		
12	Electric Impact Wrench - 1/2-in. drive - heavy duty - high amp	2
13	Electric Hammer Drill, 3/4 in. or 1 in.; heavy duty must run a 2-in. bit	2
14	2-in. x 24-in., Shaft-Flighted, Rock Bit	6
15	¾-in. x 24-in., Shaft-Flighted Hydraulic Hammer drill bits	6
16	Drill Bits, Masonry, Hammer-Drill Type, 3/4-in. Dia, 3/4-in. Drill x 12 in.	6
17	Drill Bits, Masonry, Hammer-Drill Type, 13/16-in. Dia.	6
18	Drill Bits, Masonry, Hammer-Drill Type, 2-in. Dia, 2-in. Drill x 18-24 in.	6
19	Collomix dual paddle mixer w/paddle	1
20	Concrete mixing paddles (extra)	1
21	Angle grinder - 4 in.	1
22	10-lb Sledge Hammer with non-breakable handle	2
23	Torque Wrench (150 ft-lb),1/2-in.,Clicker Version	2
24	Diesel Jerry Can, 5-Gallon	1
25	Tool Box	1
26	Tool Box Foam	1
27	4-lb Engineer's Hammer	2
28	Crow Bar	1
29	Combination wrench set - standard and metric (26 pc)	1
30	Box/Open-End Wrench, 15/16-in.	4
31	Flat-Head Screwdrivers (3 sizes)	1
32	Phillips-Head Screwdrivers (3 sizes)	1
33	4 piece plier set	1
34	Long needle nose pliers	1
35	Socket Ratchet, 12-in., 1/2-in. drive	4
36	1/2-in. drive extension - impact type	4
37	Socket, 15/16-in., ½-in. drive, Impact	12
38	Folding Ruler	2
39	Hole Saw Mandrel	2
40	2.25-in. hole saw	6
41	Angle grinder cut-off wheels	20
42	Tape Measure (25 ft)	2
43	Tape Measure (100 ft)	2
44	L5-30P to 5-20R twist lock electrical plug adapter	1
45	Wooden dowels 3/8-in.-diam x 4-ft-long tamp rod	10
46	Transmission Funnels	8
47	1.5 gallon shop vacuum	1

Table 4. (concluded)		
48	Shop vacuum micro cleaning kit	1
49	Jumper Cables	1
50	Duct Tape	4
51	Hand Broom	1
52	Tow straps	2
53	1/2-in. drill	1

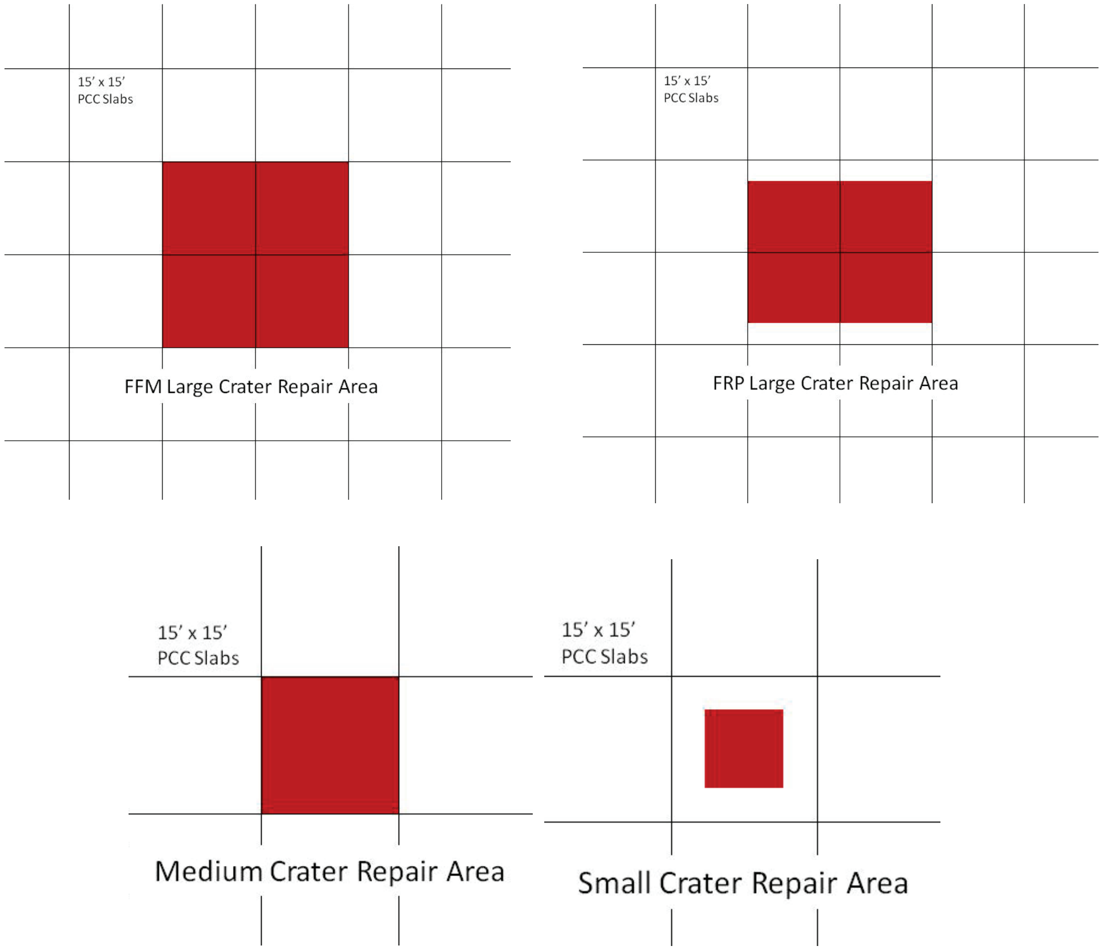
2.5.3 FFM matting kit

Select items from the FFM matting kit (USAF kit 4F9K4) were used for installation of the FFM FOD covers during the experiment. A detailed specification sheet for FFM fabrication and packaging is available (MIL-DTL-32265). Items used from this kit include tow straps, chains with end hooks, flat-nosed shovels, anchor bushings, upper joining bushings, FFM mats, and FFM joining panels. A single piece of FFM matting consists of nine 6-ft by 30-ft rigid panel sections joined with eight 3-in.-wide elastomer hinges. Overall dimensions of a single FFM mat are 30 ft by 54 ft. FFM matting is folded for shipment, handling, and storage in an accordion-style, fanfold fashion where each of the eight elastomer hinges allow the rigid sections of the FFM mat to sit atop one another. Holes to facilitate anchoring of FFM mats to the underlying pavement surface as well as joining of FFM mats to one another are cut into the entire periphery of the FFM mat. FFM mats can be joined together along either the 30-ft or 54-ft edge by employing one or a combination of the FFM joining panels from the FFM kit. Joining panels are fabricated in lengths of 24 ft and 30 ft. Joining panels have lower joining bushings pre-attached in holes cut specifically to align with the holes cut in the periphery of the FFM mats. A single 30-ft panel is needed to join FFM mats along the short dimension, while one joining panel of each size is needed to join the panels along the long dimension.

2.6 Crater preparation

For the purposes of this experiment, target crater sizes were 8-ft square, 15-ft square, and 30-ft square. The large FRP crater repair was slightly smaller in one direction to ensure sufficient overlap of the FRP assembly for anchoring purposes. Figure 10 shows the repair areas in relation to the PCC pavement slabs.

Figure 10. Repair areas for each crater size.



In preparation for the experiment, ERDC personnel used the Volvo excavator and breaker attachment to simulate damage from an explosive. A circular area was disturbed, and debris was scattered to simulate the result of an explosive impacting the pavement.

For the exercise, the equipment operators deployed to the crater site in the required equipment. The team cleared peripheral debris, identified the required repair area, and marked square lines for cutting (Figure 11). Two CTLs with the SW45 wheel-saw attachments then began to simultaneously cut parallel lines in opposite directions (Figure 12). After completing the first cuts, the CTLs were repositioned, and the adjacent parallel lines were cut with the saws operating in opposite directions.

Figure 11. Marking crater repair area.

Figure 12. Sawing crater repair area.

Once cutting was complete, the Volvo excavator with the breaker attachment was used to break the PCC surface into bucket-sized pieces by repositioning the breaking head on the pavement surface (Figure 13). Once complete, the Volvo excavator with the bucket attachment was used to scoop the chunks of concrete and place them adjacent to the crater (Figure 14). The operator continued to excavate the crater until the depth was uniform and at least 18 in. below the pavement surface.

Figure 13. Breaking crater repair area.

Figure 14. Removing debris using bucket attachment.

Once the final depth was achieved, the subgrade material in the bottom of the crater was compacted using two MultiQuip MTX-60 jumping jack compactors. Next, limestone base course material was placed in 6-in. lifts and compacted using the MultiQuip MTX-60s (Figure 15). Three lifts were compacted to achieve the total 18-in. repair thickness. The CTL with bucket attachment was used to ensure the surface was at final grade.

Figure 15. Compacting limestone with MultiQuip MTX-60.

2.7 Matting installation

Once the crater repairs were completed, the FOD covers were installed to determine timing and personnel requirements for both systems (FFM and FRP). Small and medium craters with FFM covers included a single panel. The large crater with FFM required two panels. The FRP covers were installed using the necessary components to cover the crater. Examples of the assemblies for FFM and FRP are shown in Figure 16 through Figure 19. Details of the installation of FOD covers are provided in Chapter 4.

2.8 Anchor installation

Following the placement of matting as described in Section 2.7, the FOD covers were anchored to the pavement using one of three anchor systems. For PCC pavements, the Power Bolt 6957 anchor bolt was used. For AC pavements, both the legacy type B-3 polymer glue asphalt anchors as well as the Tri-Talon Anchor (TTA) system were used.

Figure 16. FRP full matting assembly for large crater.

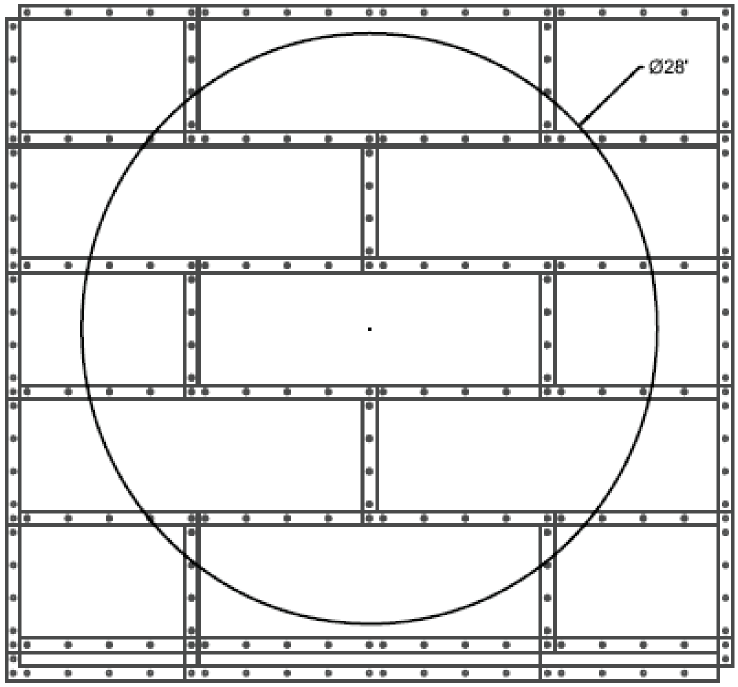


Figure 17. FRP assembly for medium and small craters.

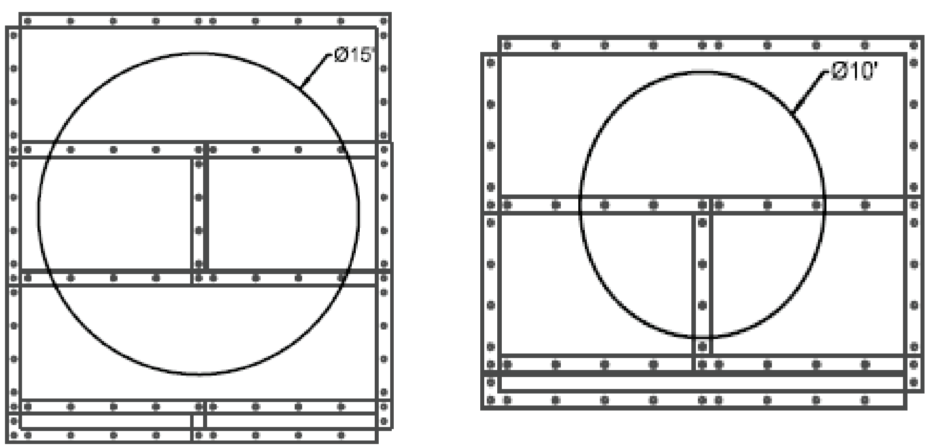


Figure 18. Single panel FFM for small and medium craters.

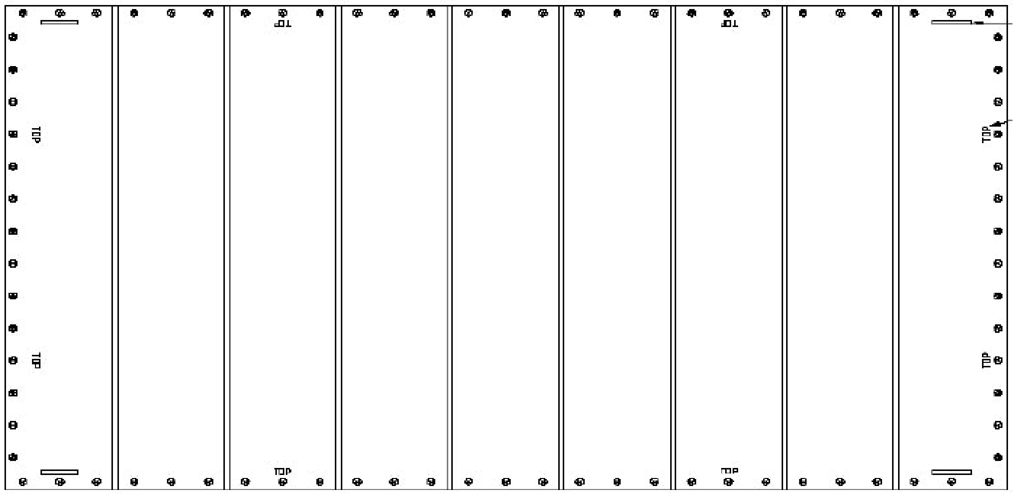
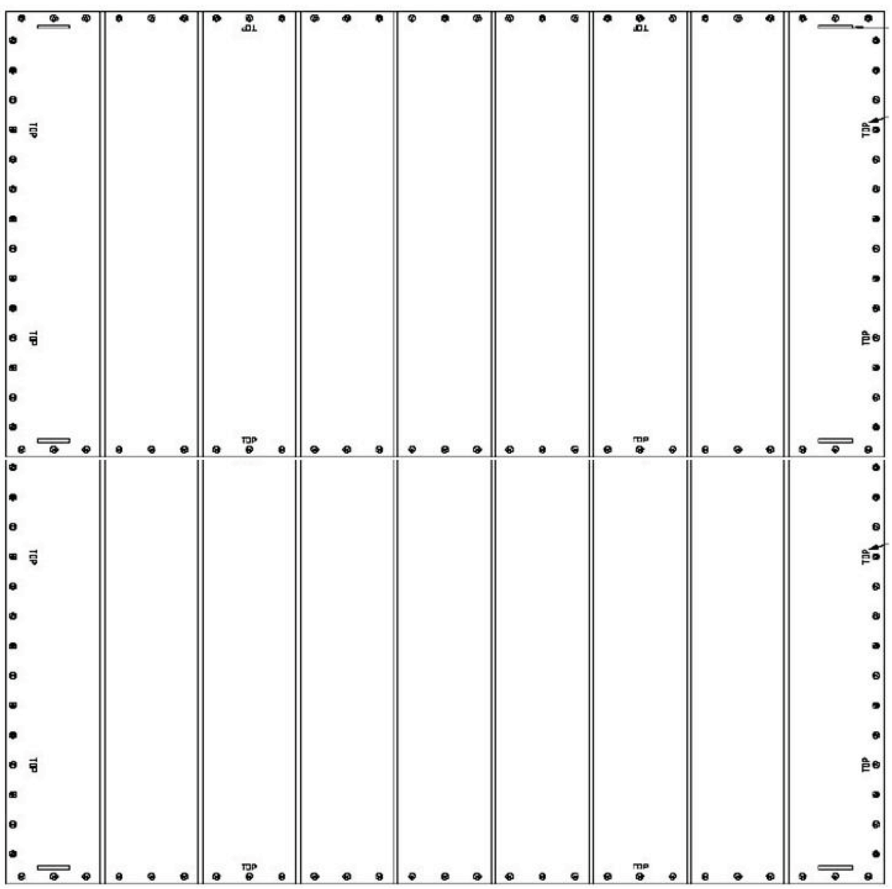


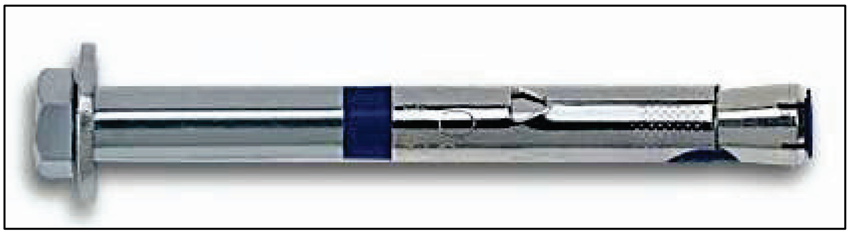
Figure 19. Double panel FFM for large craters.



2.8.1 Power Bolt 6957 anchor

The Powers Fastener anchor bolt (part number 06957) is a ¾- x 8¼-in. COTS product that has been used extensively for anchoring to PCC surfaces. The anchor consists of a threaded bolt housed in a sleeve with a specially designed expanding attachment secured to the base of the anchor. This attachment expands as torque is applied to the anchor bolt after placement into the anchor hole to effectively secure the Power Bolt in place. Figure 20 is a photograph of the Powers Bolt 6957.

Figure 20. Powers Bolt 06957 (Powers Fasteners, Inc.).



The installation sequence for the Powers Bolt 6957 is as follows.

1. Using a hammer drill with a ¾-in.-diameter drill bit, drill to a depth of at least 9 in.
2. Using compressed air, clear all debris from the anchor hole.
3. Remove the washer from Powers Bolt 6957, replace with an anchor bushing, and reattach sleeve/expanding attachment to the bolt.
4. Force the bolt into the anchor hole carefully to avoid deployment of the expanding attachment at the base of the bolt. Use of a hammer may be necessary.
5. Using an impact wrench apply torque to the anchor bolt head to deploy the expanding attachment and secure the anchor.

2.8.2 Type B-3 polymer glue anchor

The type B-3 polymer glue anchor system utilizes the same Powers Bolt 6957 anchor described in Section 2.8.1 (Figure 20). However, the anchor is installed using a different installation technique more suited to asphalt pavements. Following the drilling of the anchor hole into the asphalt pavement, a high-strength, two-part epoxy polymer glue is introduced into the anchor hole. Following introduction of the polymer glue, the anchor bolt (having already been threaded through the anchor bushing) is placed into the anchor hole. Once the polymer glue material has sufficiently hardened, the anchor bolt may be tightened.

The installation sequence for the type B-3 polymer glue anchor is as follows.

1. Using a hammer drill with a 1.5-in.-diameter drill bit, drill to a depth of approximately 10 in.
2. Using compressed air, clear all debris from the anchor hole.
3. After mixing the polymer glue, fill the anchor hole with the polymer glue until approximately ½ in. below the existing pavement surface.
4. Remove washer from Powers Bolt 6957, replace with anchor bushing, and reattach sleeve/expanding attachment to bolt.
5. Place bolt into anchor hole, removing the displaced polymer.
6. Once the polymer glue material has hardened, tighten the anchor bolt using an electric impact wrench to secure the anchor.

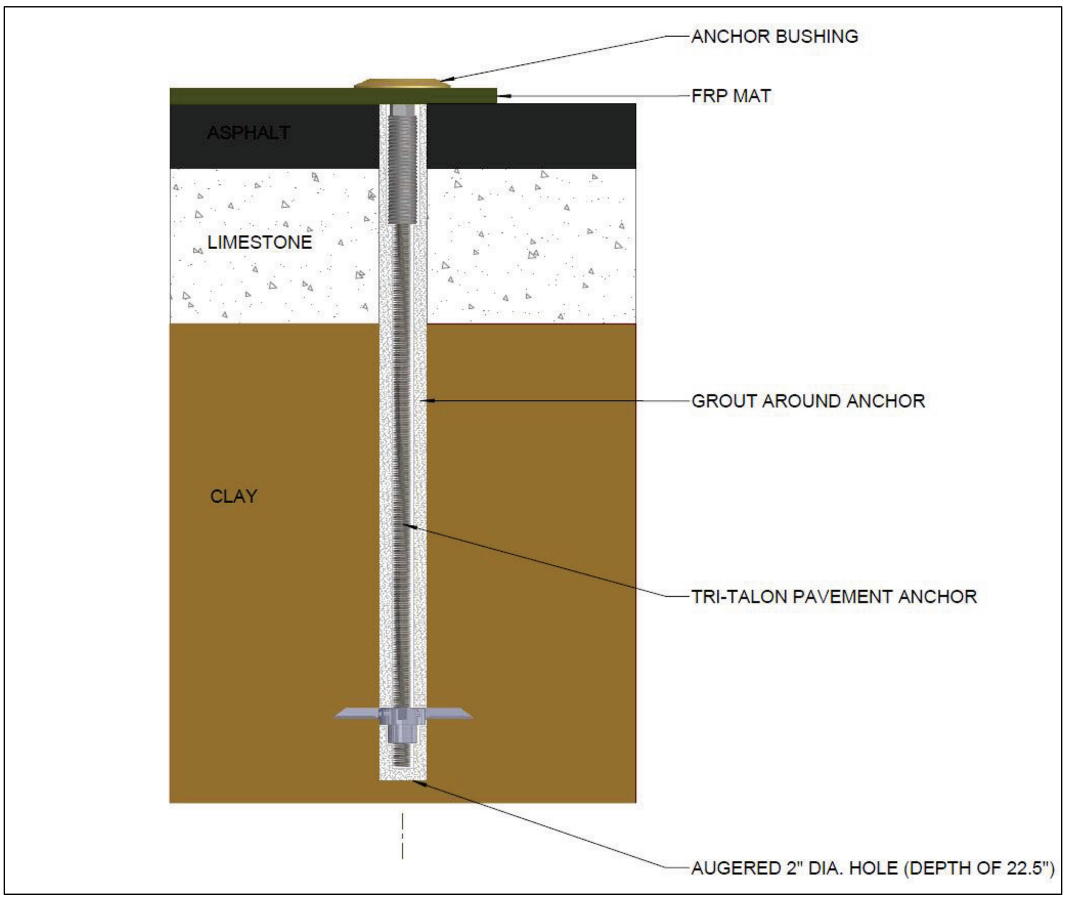
2.8.3 Tri-Talon anchor

Development of the Tri-Talon anchor system and previous design iterations are discussed in Gartrell 2007 and Gartrell 2008. The original design included components made from proprietary threaded rods that were relatively expensive and could only be procured from a single source. In an effort to increase competition in manufacturing and reduce anchor costs, the Tri-Talon anchor system was re-designed using a commercial-off-the-shelf (COTS) B7 threaded rod. However, since the original system had been certified under live-flight aircraft conditions (Priddy et al. 2011), the performance of the new design needed to be verified to be equivalent to that of the old design. A series of tests were conducted to validate the strength of the new design and to determine the vertical pull-out resistance of the Tri-Talon anchor system in asphalt pavements of various material compositions, structures, strengths, and thicknesses (Rushing et al. [in preparation]). An image of the Tri-Talon anchor is shown in Figure 21.

Each anchor consists of (from bottom to top) a retaining ring, the Tri-Talon, the threaded anchor rod, the special anchor coupling (connecting the rod and anchor bolt), and the anchor bolt. Detailed drawings of the Tri-Talon anchor system are in Rushing et al. (in preparation.) The primary advantage of the Tri-Talon anchor system is its use of the entire pavement structure to resist vertical pull-out. Figure 22 shows an overall schematic of an installed Tri-Talon anchor.

Figure 21. Tri-Talon Anchor.

Figure 22. Tri-Talon anchor schematic.



The installation sequence for installing Tri-Talon anchors in asphalt concrete pavement is as follows.

1. Using a hammer drill with a 2-in.-diameter bit, drill through the pavement surface and compacted subbase.
2. Using a hydraulic power unit and a 2-in.-diameter soil auger bit, auger to a depth of approximately 22.5 in.
3. After removing the coupler and bolt from the top of a Tri-Talon anchor, insert the threaded rod into the anchor hole.
4. Place the Tri-Talon set tool onto the threaded rod and deploy the talons by striking the set tool sharply with a sledge hammer.
5. Reattach the coupler and bolt to the threaded rod and adjust the coupler height to approximately flush with the pavement surface using an impact wrench.
6. Mix the rapid-setting grout per instructions and use a funnel to fill the anchor hole with rapid-setting grout to approximately flush with the pavement surface.
7. Once the grout has set, remove anchor bolt from coupler and install matting.

3 Crater Repair Using Crushed Stone Backfill Method

The crater repair team performed the crater repairs according to the crushed stone backfill method using the equipment described in Chapter 2. During the crater repair process, each step was monitored to collect timing data to support ADR planning documents. The following discussion provides details of the repair process and data collected during the experiment.

3.1 Saw cutting

After the surface debris was removed and the upheaval marked, two CTLs with the SW 45 wheel-saw attachments saw cut opposite sides of the crater repair while operating in opposite directions (Figure 12). The time required to cut the perimeter of the repair area was influenced by the type of pavement surface and its thickness. Because the experiment area is frequently used for testing, the pavement surface material and thickness varied by location. The typical pavement thickness was 10 in., and the surface was typically ordinary Portland cement concrete. Saw-cutting rates were calculated by dividing the total length of the saw cut by the time required to complete the cut. Table 5 provides cutting rates for each repair.

Table 5. Cutting rate on crater repairs.

Crater	Dimension	Average Cut Rate (ft per min)
1	8 ft x 8 ft	2.15
2	8 ft x 8 ft	2.27
3	15 ft x 15 ft	2.61
4	15 ft x 15 ft	2.57
5	24 ft x 30 ft	2.01
6	30 ft x 30 ft	2.24
	Average	2.31

The average cutting rate during the demonstration was 2.31 ft per min. This average is consistent with previous measurements from a similar effort at the Silver Flag Exercise Site (Bell et al. 2013). The cutting rate was not greatly affected by the crater size, as expected. The time to saw the crater perimeter can be estimated using a linear regression equation for a given pavement thickness.

3.2 Pavement breaking

Breaking the upheaved pavement was accomplished using the Volvo Wheeled Excavator with the breaker attachment (Figure 23). The goal of the breaking process was to fracture the upheaved pavement surface into manageable pieces that could be removed using the excavator with a bucket attachment or the CTL with a bucket attachment. Table 6 provides the timing data from the breaking procedure for each crater.

Table 6. Breaking time for crater repairs.

Crater	Dimension	Total Breaking Time (min)
1	8 ft x 8 ft	8
2	8 ft x 8 ft	3
3	15 ft x 15 ft	3
4	15 ft x 15 ft	3
5	24 ft x 30 ft	36
6	30 ft x 30 ft	41

Timing data for the pavement breaking procedure show that the small and medium craters required similar times to fracture the pavement surface. These data are slightly longer than that reported by Bell et al. (2013), but the operators were not as experienced as those in the previous experiment. The large craters took significantly longer to break the pavement surface. The time required was not directly proportional to the crater size. The surface of the large craters was four times that of the medium craters, but the breaking required twelve times as long. This is partly due to the fact that the intact pavement area (not disturbed in the initial crater) was greater with larger intact pieces. However, Carruth et al. (2015) found that large craters required approximately 15 min for breaking. The main reason for the longer breaking times on large craters is thought to be related to the inexperience of the operator trying to become familiar with the equipment. The breaking procedure is one of the faster processes, and as such, the breaker would not be a constraining point in the repair process because it takes longer to saw and excavate a crater than it does to break the surface.

Figure 23. Large crater repair area.

3.3 Excavation

The Volvo Wheeled Excavator with the bucket attachment was used to excavate the debris from the crater (Figure 14). The goal of the excavation process was to remove the pavement surface and subgrade soil to a depth of 18 in. below the pavement surface. Table 7 provides the timing data from the excavation procedure for each crater.

Table 7. Excavation time for crater repairs.

Crater	Dimension	Total Excavation Time (min)	Cubic Feet Per Minute Removed
1	8 ft x 8 ft.	36	2.7
2	8 ft x 8 ft	25	3.8
3	15 ft x 15 ft	29	11.6
4	15 ft x 15 ft	34	9.9
5	24 ft x 30 ft	72	18.8
6	30 ft x 30 ft	54	25.0

Timing data for the excavation procedure show that excavation efficiency increases as the crater size increases. The bucket size is rather large for the smallest crater. The fastest part of excavation is removal of the material from the center of the crater. Additional precision is required to trim the edges to leave a vertical face along the crater repair walls. The increase in efficiency with crater size is related to the greater proportion of material that does not require that level of precision.

3.4 Crushed stone backfill

The crushed stone backfill was installed in three 6-in. lifts. The first two lifts were compacted with the MultiQuip MTX-60 jumping jack compactors. The final lift was compacted with a self-propelled vibratory steel wheeled roller. The timing data for installing crushed stone backfill are given in Table 8.

Table 8. Installation time for stone backfill.

Crater	Lift 1 Placement	Lift 1 Compaction	Lift 2 Placement	Lift 2 Compaction	Lift 3 Placement	Lift 3 Compaction	Total
1	10	7	8	6	6	2	39
2	4	5	5	4	8	2	28
3	13	14	13	7	16	20	83
4	14	13	12	10	16	27	92
5	59	12	52	11	37	38	209
6	45	9	23	12	65	42	196

Timing data for the backfill procedure show that the effort is proportional to the crater diameter. The 15-ft crater required approximately twice the time as the 8-ft crater, and the 30-ft crater required approximately twice the time as the 15-ft crater. Note that the volume of material required to fill the 30-ft crater is four times that of the 15-ft. crater, so the backfill procedure becomes more efficient as the crater size increases.

4 FOD Cover Installation

4.1 FFM installation

4.1.1 Small crater (8 ft x 8 ft) over PCC pavement

The FFM small assembly over PCC pavement took place on 30 August 2015 using an eight-man team to unfold the mat and a 14-man team to install the anchors. The purpose of varying the team size for this exercise was to demonstrate a real scenario where the equipment operators had completed the crater repair and then were inserted into the matting team to assist with final installations. This was the only experiment where additional manpower was used. The assembly was prepared adjacent to the crater previously repaired by the heavy-equipment operators using the crushed stone backfill method.

The small FFM crater repair covered an area of 54 ft by 30 ft due to the size of the FFM mat. According to the data in Table 9, the total repair process required 36 min. Most of the time is consumed in the anchoring process; the mat was unfolded and positioned over the crater in 7 min. Twenty-six min were required to install 54 anchors.

Table 9. FFM assembly time for small PCC repair.

Time	Event
0:00	Unloaded mats
0:04	Unfolding mats
0:07	Mat aligned over crater
0:10	Begin drilling anchor holes
0:26	Approximately half of anchors complete
0:36	Assembly complete

4.1.2 Small crater over AC pavement

The FFM small assembly over AC pavement took place on 1 September 2015 using an eight-man team. The assembly was prepared on top of the repair area. An actual crater was not created to avoid damaging the AC pavement. A representative crater area was marked as the appropriate location for the repair.

The small FFM crater repair covered an area of 54 ft by 30 ft due to the size of a single FFM panel. According to the data in Table 10, the total repair process required 33 min. Only half of the anchors were installed in the AC pavement. From the data in Table 10, it can be estimated that the total repair time for installing all anchors would have been approximately 59 min. Most of the time was consumed in the anchoring process; the mat was unfolded and positioned over the crater in 6 min. Twenty-six min were required to install 27 Tri-Talon anchors.

Table 10. FFM assembly time for small AC repair.

Time	Event
0:00	Unloaded mats
0:03	Mat unfolded
0:06	Mat positioned over crater
0:07	Begin drilling pilot holes
0:14	Pilot holes complete
0:21	Half of anchor holes drilled/begin pouring epoxy
0:32	All holes drilled/continue pouring epoxy
0:33	Assembly complete
0:59	Extrapolated repair time for entire crater repair

4.1.3 Medium crater (15 ft x 15 ft) over PCC pavement

The FFM medium-sized assembly over PCC pavement took place on 30 August 2015 using an eight-man team. The assembly was prepared adjacent to the crater previously repaired by the crater repair team using the crushed stone backfill method.

The medium FFM crater repair covered an area of 54 ft by 30 ft due to the size of the FFM panel. According to the data in Table 11, the total repair process required 46 min. Most of the time was consumed in the anchoring process; the mat was unfolded and positioned over the crater in 5 min. Thirty-four min were required to install 54 Powers Bold anchors. The remaining time was for removing the extra panel and preparing for drilling.

Table 11. FFM assembly time for medium PCC repair.

Time	Event
0:00	Unloaded mats
0:04	Top panel removed
0:05	Begin unfolding FFM
0:10	FFM positioned over crater
0:12	Begin drilling anchor holes
0:25	Approximately half of anchors installed
0:46	Assembly complete

4.1.4 Large crater (30 ft x 30 ft) over PCC pavement

The FFM large assembly over PCC pavement took place on 1 September 2015 using an eight-man team. The assembly was prepared adjacent to the crater previously repaired by the crater repair team using the crushed stone backfill method.

The large FFM crater repair covered an area of 54 ft by 60 ft. According to the data in Table 12, the total repair process required 68 min. About half the time was consumed in the anchoring process; the mat was unfolded and positioned over the crater in 29 min. The extended period of time for assembling and positioning the mat is related to the effort involved in joining the two FFM panels. Thirty-eight min were required to install 54 anchors.

Table 12. FFM assembly time for large PCC repair.

Time	Event
0:00	Unloaded mats
0:05	First mat unfolded
0:10	Connector panel installed
0:19	Two mats connected
0:23	First drag complete
0:27	Second drag complete
0:29	Final positioning complete
0:30	Begin drilling anchor holes
0:45	Anchors installed on side one
1:01	Drilling complete
1:06	Impacting anchors complete
1:08	Assembly complete

4.2 FRP installation

4.2.1 Small crater (8 ft x 8 ft) over PCC pavement

The FRP small assembly over PCC pavement took place on 30 August 2015 using an eight-man team. The assembly was prepared on top of the crater that was previously repaired by the crater repair team using the crushed stone backfill method.

The small crater repair covered an area 18 ft by 13 ft. According to the data in Table 13, the total repair process required 17 min. Most of the time was consumed in the anchoring process; the mats were assembled in 3 min. Twelve min were required to install 20 Powers Bolt anchors. The remaining time was for tightening connectors.

Table 13. FRP assembly time for small PCC repair.

Time	Event
0:00	Unloaded mats
0:02	First panel aligned over crater
0:03	Mat assembled
0:05	Begin drilling anchor holes
0:17	Assembly complete

4.2.2 Small crater in AC pavement

The FRP small assembly over AC pavement took place on 1 September 2015 using an eight-man team. The assembly was prepared on top of the repair area. An actual crater was not created to avoid damaging the AC pavement. A representative crater area was marked as the appropriate location for the repair.

The small crater repair covered an area 18 ft by 13 ft. According to the data in Table 14, the total repair process required 46 min. Most of the time was consumed in the anchoring process; the mats were assembled in 2 min. Forty-two min were required to install 20 Tri-Talon anchors.

Table 14. FRP assembly time for small AC repair.

Time	Event
0:00	Unloaded mats
0:01	Begin assembly
0:03	Mat assembled
0:04	Begin drilling pilot holes
0:07	Side one pilot holes complete/switch to rock drill
0:11	Drilling 2-in. holes side two/augering side one
0:27	Begin installing tri-talons on side one
0:31	All holes augered on side two
0:35	Tri-talons set on side one
0:39	Begin filling side one with grout
0:40	Begin filling side two with grout
0:45	All grout installed
0:46	Assembly complete

4.2.3 Medium crater (15 ft x 15 ft) over PCC pavement

The FRP medium assembly over PCC pavement took place on 30 August 2015 using an eight-man team. The assembly was prepared adjacent to the crater previously repaired by the crater repair team using the crushed stone backfill method.

The medium FRP crater repair covered an area 18 ft by 19 ft. According to the data in Table 15, the total repair process required 25 min. Most of the time was consumed in the anchoring process; the mats were assembled in 3 min. Fourteen min were required to install 20 Powers Bolt anchors. The remaining time was for tightening connectors and positioning the mat over the crater.

Table 15. FRP assembly time for medium PCC repair.

Time	Event
0:00	Unloaded mats
0:01	Begin assembly
0:04	Mat assembled
0:06	Positioning mat using 10k Extendable forklift
0:11	Begin drilling anchor holes
0:19	Side one anchor holes drilled
0:20	Begin tightening side one with impact drill
0:21	Side one anchoring complete
0:25	Assembly complete

4.2.4 Large crater (22 ft x 30 ft) over PCC pavement

The FRP large assembly over PCC pavement took place on 1 September 2015 using an eight-man team. The assembly was prepared on top of the crater previously repaired by the crater repair team using the crushed stone backfill method.

The large FRP crater repair covered an area 35 ft by 31 ft. According to the data in Table 16, the total repair process required 50 min. Most of the time was consumed in the anchoring process; the mats were assembled in 17 min. Thirty min were required to install 40 Powers Bolt anchors.

Table 16. FRP assembly time for large PCC repair.

Time	Event
0:00	Unloaded mats
0:01	Begin assembly
0:03	First row assembled
0:07	Second row assembled
0:13	Fourth row assembled
0:15	Fifth row assembled
0:18	Anchor panels installed
0:20	Begin drilling anchor holes
0:41	Anchors installed on side one
0:45	All anchors installed
0:48	Side one anchors torqued
0:50	Assembly complete

4.2.5 Large crater over AC pavement

The FRP large assembly over AC pavement took place on 29 August 2015 using an eight-man team. An actual crater was not created to avoid damaging the existing AC pavement. A representative crater area was marked as the appropriate location for the repair.

The large FRP crater repair included the full assembly and covered an area 35 ft by 31 ft. According to the data in Table 17, the total repair process required 2 hr and 12 min. Most of the time was consumed in the anchoring process; the mats were assembled in 16 min. It required 102 min to install 40 Tri-Talon anchors.

Table 17. FRP assembly time for large AC repair.

Time	Event
0:00	Begin assembly
0:02	First row assembled
0:04	Second row assembled
0:08	Third row assembled
0:11	Fourth row assembled
0:16	Assembly complete
0:20	Begin positioning mat over crater
0:30	Mat positioned over crater
0:54	All holes drilled on side one
1:01	All holes augered on side one
1:18	Tri-talons set on side one
1:34	All holes augered
1:58	Begin filling side one with grout
2:05	Side one complete
2:12	Assembly complete

4.2.6 Additional data

During the FRP training exercise, the airmen were tasked with practicing assembly of multiple configurations to collect additional data. The data included the time from unloading the mat assembly from the truck to the point when the panels were placed and joined with connector bushings. No anchor installations were performed during this training. The intent of this training exercise was to allow the airmen to become more familiar with the FRP matting system and to provide information on manpower and time requirements for assembling multiple small crater repairs.

The first training exercise involved putting together one full FRP mat assembly using an eight-man team. The forklift removed the matting bundle from the transport truck. Half panels could be moved by four men. Removing full panels from the bundle required six men. Therefore, only two men were available for unpacking and installing bushings until the required mats were removed from the packing bundle. Once the team began assembling the mat, the entire full assembly was completed in 16 min.

The next training exercise involved putting together three medium mat assemblies using the eight-man team. The three repairs were performed in a row with about 10-ft spacing between the mats. In a real scenario, the crater repairs would be spaced farther apart. The time to drive the team and forklift with the matting bundle to the next site would need to be included for a full analysis. Using this scenario, the first mat assembly was completed in 7 min. After that mat was assembled, the team moved positions and began the next assembly, which was completed in 3 min. The final assembly also required an additional 3 min. The longer time required for the first assembly was caused by the added time in removing the bundle from the haul truck and positioning over the target location.

The final training exercise involved putting together five small mat assemblies using the eight-man team. The five repairs were also performed in a row with a 10-ft spacing between the mats. Using this scenario, the first mat assembly was completed in 4 min. After that mat was assembled, the team moved positions and began the next assembly, which was completed in 2 min. The final three assemblies also required an additional 2 min.

Overall, the FRP panels were easily aligned and joined using the eight-man team. This team size was effective since the large panels required a minimum of six men to transport. The additional two men were useful in operating the forklift to position the mat bundle and for unpacking the joining bushings. The time required to assemble the FRP crater repairs was proportional to the size of the repair. Assembling the large repair required 16 min, while the three medium and five small repairs required 13 and 12 min, respectively. As the assembly size decreases, so does the number of joining bushings, therefore making assembly faster.

5 Simulated Aircraft Traffic

5.1 Description of the load carts

5.1.1 F-15E load cart

A specially designed single-wheel load cart was used to simulate F-15E aircraft traffic. The load cart was equipped with a 36-in. by 11-in. tire inflated to 325 lbf/in.^{2} and loaded such that the test wheel was supporting 35,235 lb. A photograph of the load cart is shown in Figure 24.

Figure 24. F-15E load cart.

5.1.2 C-17 load cart

The multiple-wheel C-17 load cart was designed to exactly match one-half of the full main gear of a C-17 aircraft. The multiple-wheel C-17 load cart was equipped with six 50 in. x 21 in. tires inflated to 142 lbf/in^2. The cart was loaded with lead weights so that the test gear was supporting approximately 269,000 lb. A photograph of the load cart is shown in Figure 25.

Figure 25. C-17 load cart.

5.2 Traffic operations

A normally distributed pattern of simulated traffic was applied in a 3.75-ft-wide traffic area for the F-15E tests and a 9-ft-wide traffic lane for the C-17 tests. The traffic area was broken into lanes that were designed to simulate the traffic distribution pattern, or wander width, of the main landing gear wheel when operating on a runway or taxiway. The normally distributed traffic patterns were simplified for ease-of-use by the load cart operator. Traffic was applied by driving the load cart forward and then backward over the length of the test item and then shifting the path of the load cart laterally approximately one tire width on each forward pass. Tracking guides were attached to assist the driver in shifting the load cart the proper amount for each forward pass. This procedure was continued until one pattern of traffic was completed. One pattern resulted in 16 passes for the F-15E traffic and 28 passes for the C-17 traffic. Figure 26 and Figure 27 show the typical traffic pattern for the F-15E and C-17, respectively.

Figure 26. F-15E traffic pattern.

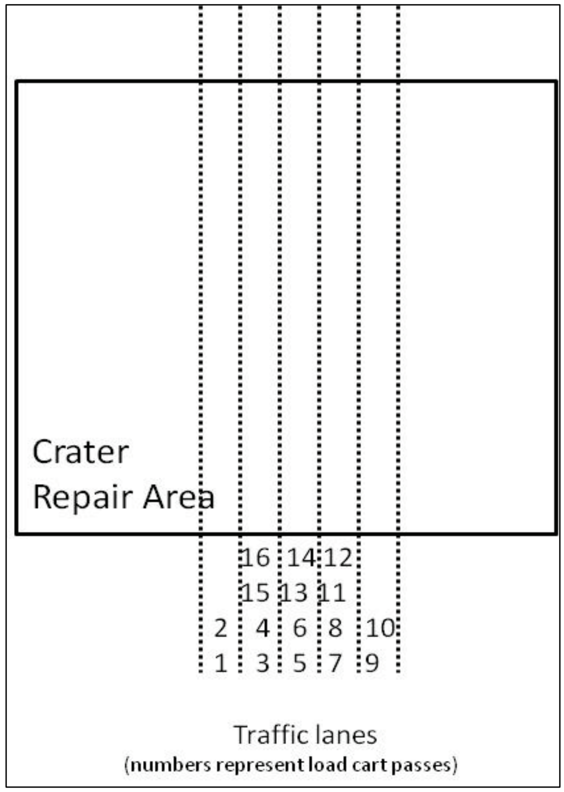
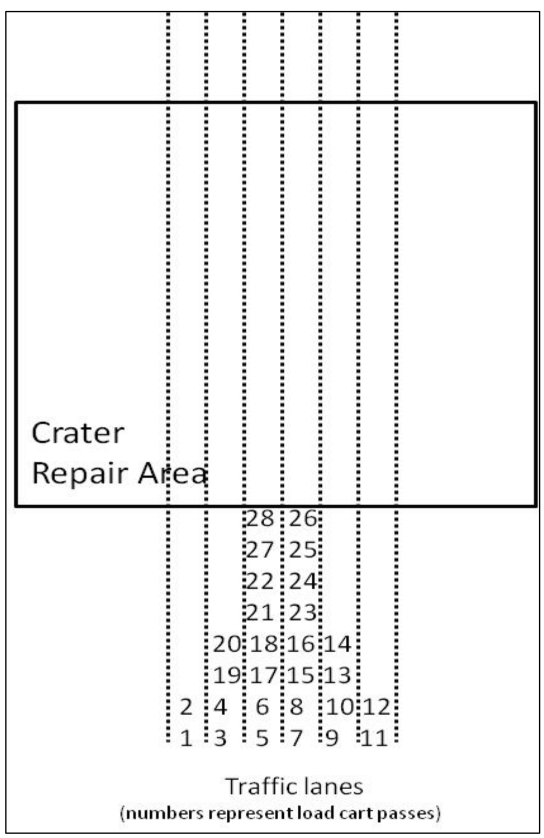


Figure 27. C-17 traffic pattern.



5.3 Data collection

Surface elevations were taken laterally using a rod and level across the repair areas in three locations to monitor permanent deformation. Data were collected after each traffic pattern for the two different load carts. A total of 64 passes were made using the F-15E load cart; 84 passes were applied with the C-17 load cart. The mats were constantly monitored for any damage during trafficking.

The F-15E loads typically cause surface damage because of the high tire pressure. In all cases, rutting was observed after 64 passes of the F-15E traffic. Once the traffic pattern was completed, the mats were removed, and new stone was applied to the developed ruts to bring the surface elevation back closer to level. This practice was intended to represent crater maintenance that would be required in a real scenario. C-17 traffic was applied after the maintenance procedures were performed. After all traffic was completed, the mats were removed and surface elevations were taken on the crushed stone repair surface. Figure 28 through Figure 51 provide center cross-section measurements for each repair.

Figure 28. Elevations versus passes for F-15E on small FFM repair.

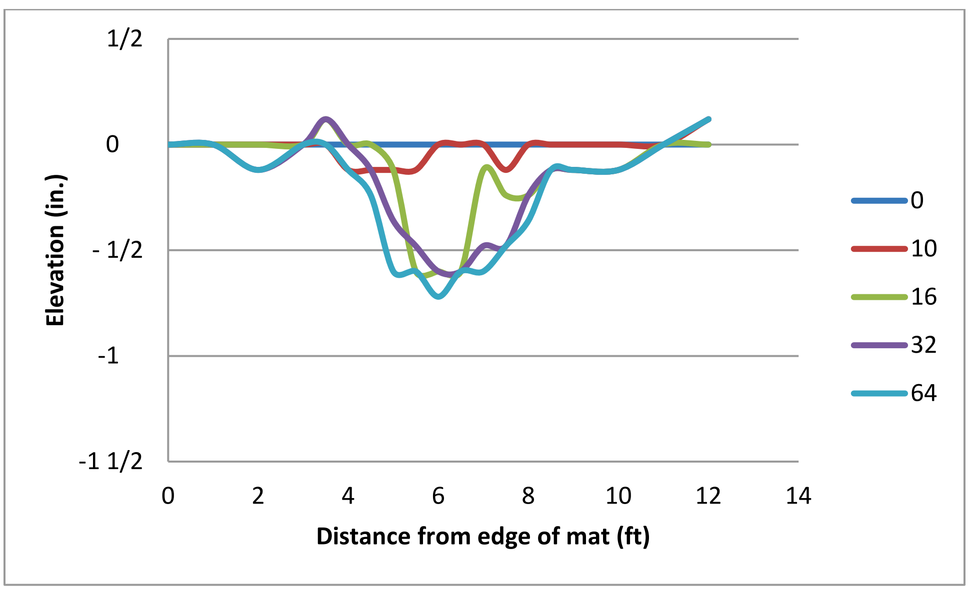


Figure 29. Elevations versus passes for F-15E on small FFM repair (mat removed).

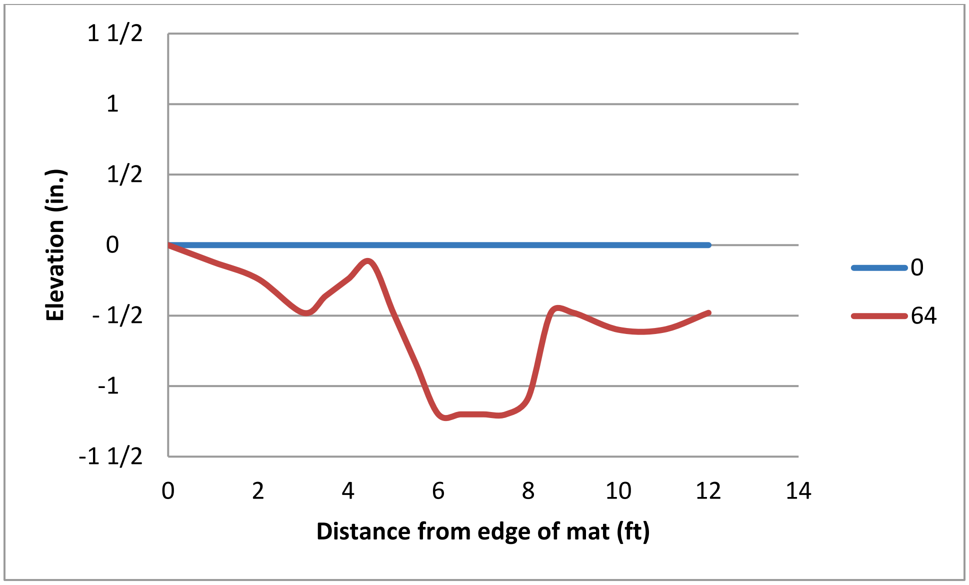


Figure 30. Elevations versus passes for C-17 on small FFM repair.

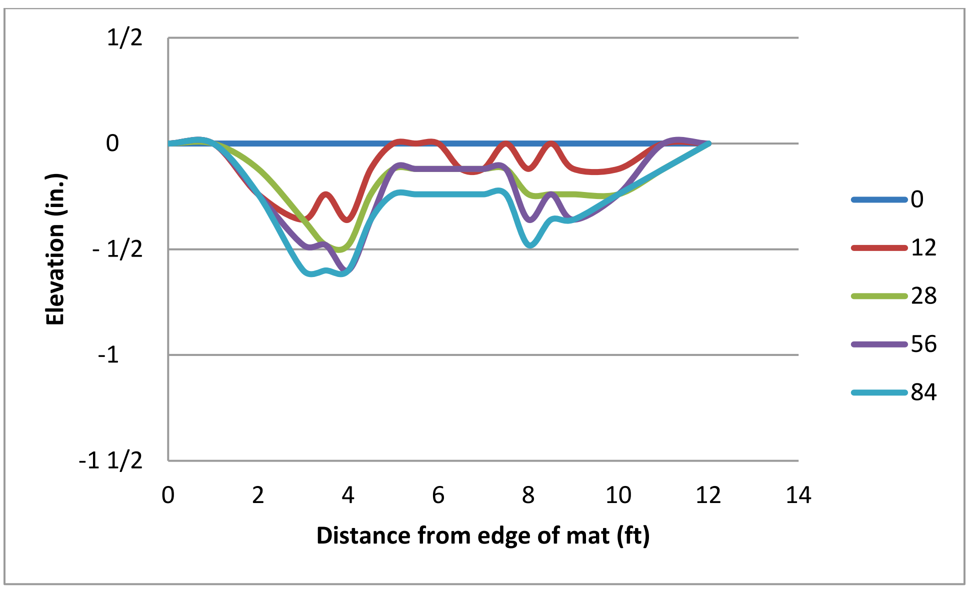


Figure 31. Elevations versus passes for C-17 on small FFM repair (mat removed).

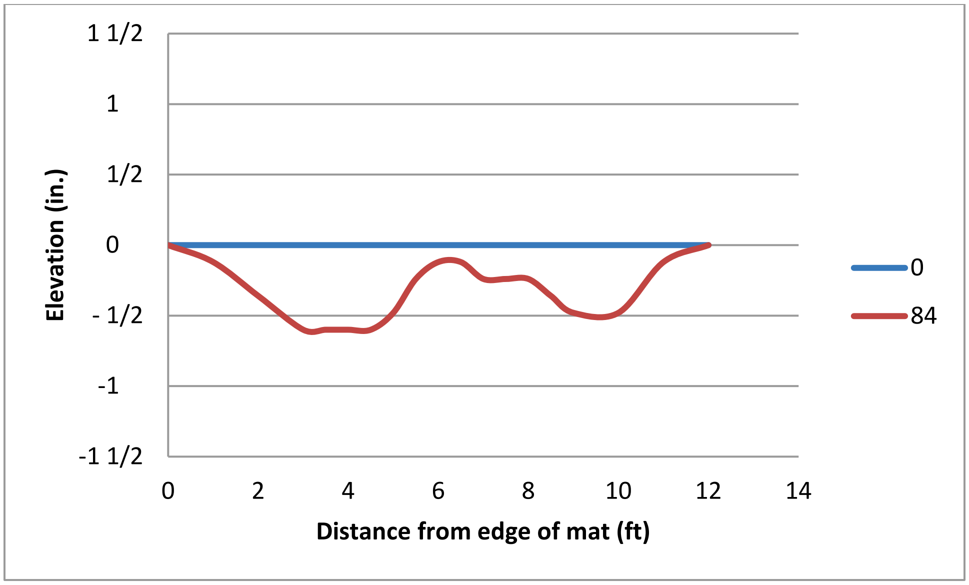


Figure 32. Elevations versus passes for F-15E on medium FFM repair.

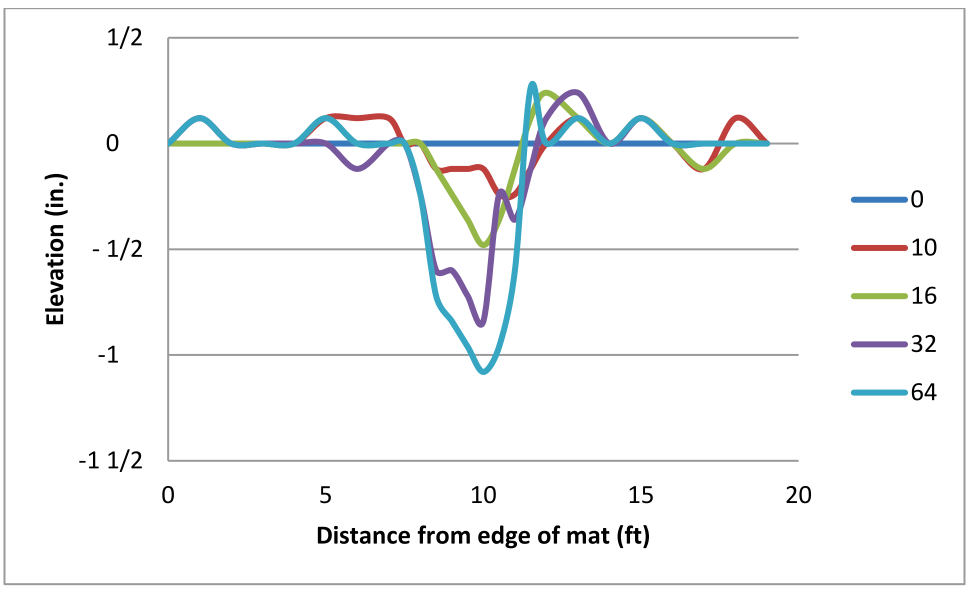


Figure 33. Elevations versus passes for F-15E on medium FFM repair (mat removed).

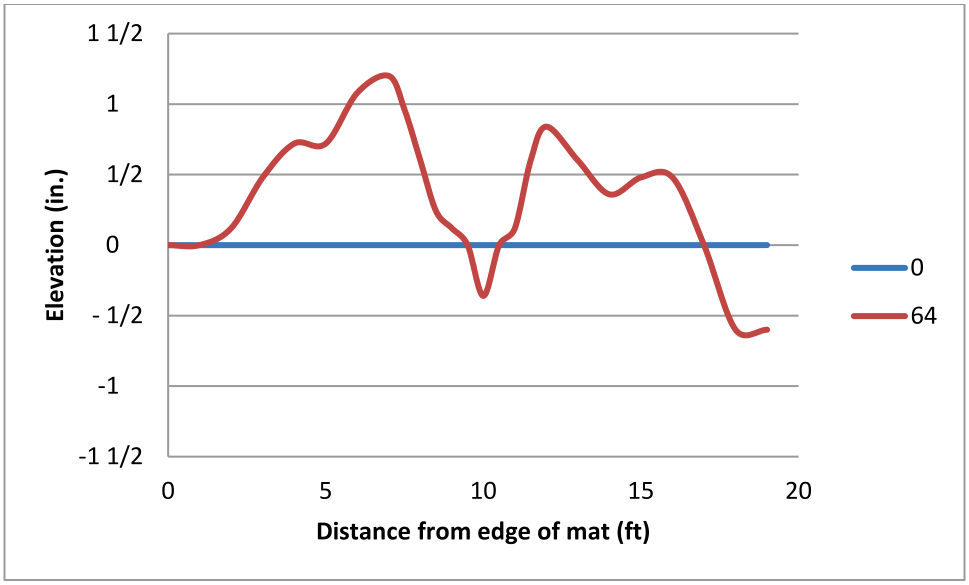


Figure 34. Elevations versus passes for C-17 on medium FFM repair.

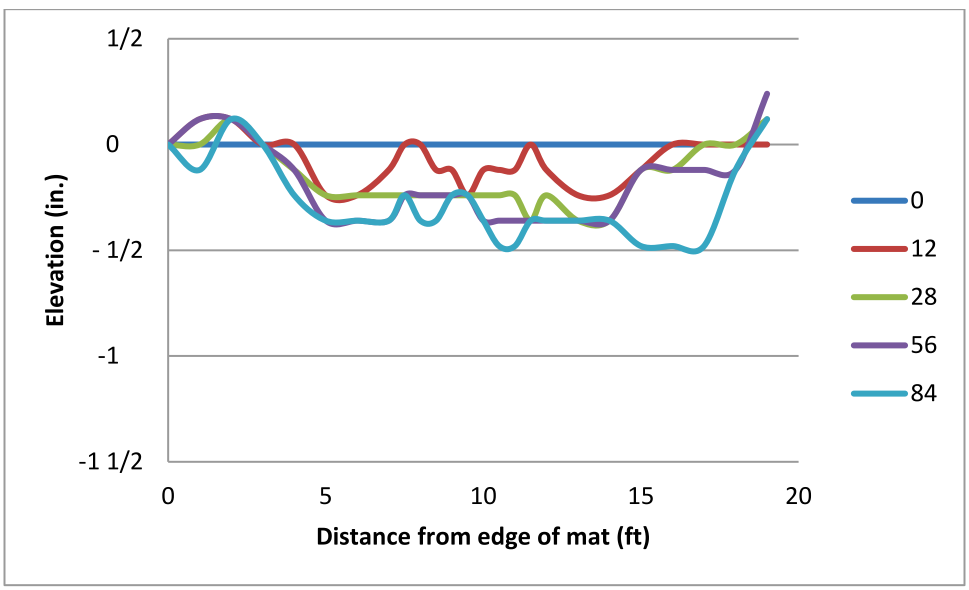


Figure 35. Elevations versus passes for C-17 on medium FFM repair (mat removed).

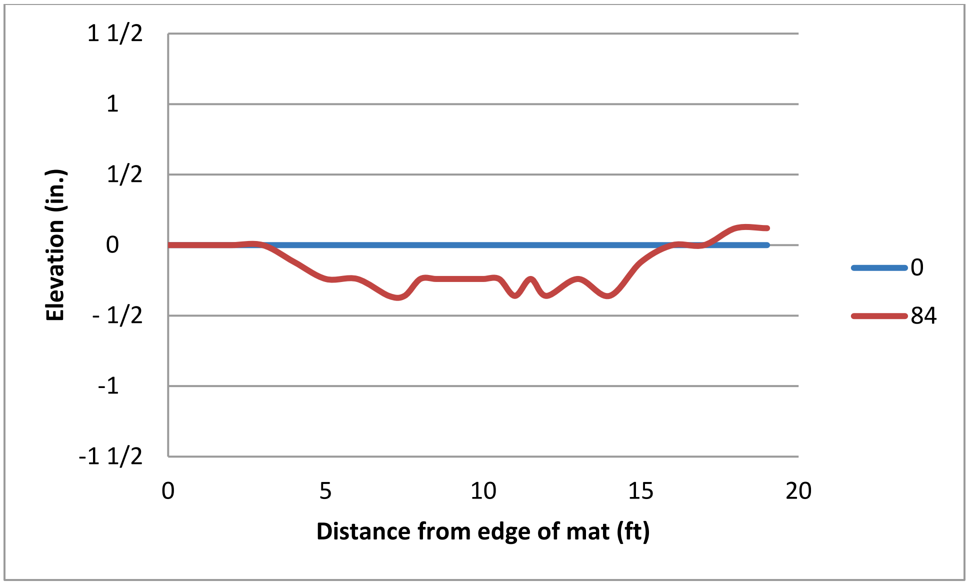


Figure 36. Elevations versus passes for F-15E on large FFM repair.

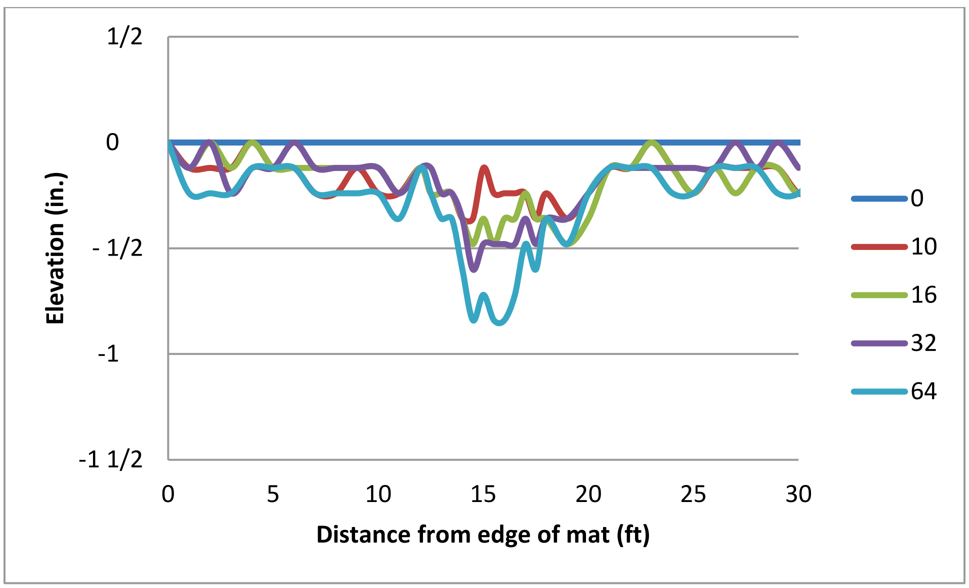


Figure 37. Elevations versus passes for F-15E on large FFM repair (mat removed).

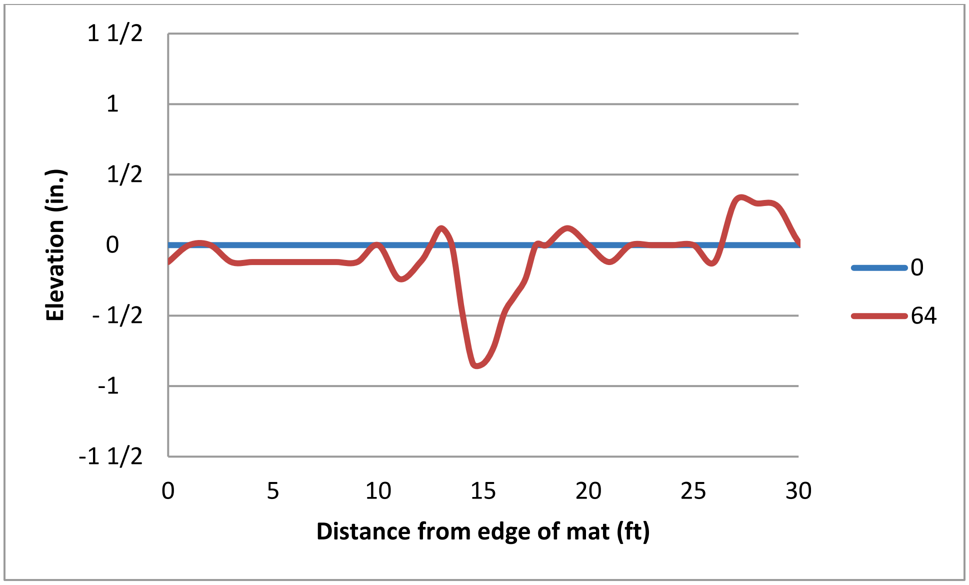


Figure 38. Elevations versus passes for C-17 on large FFM repair.

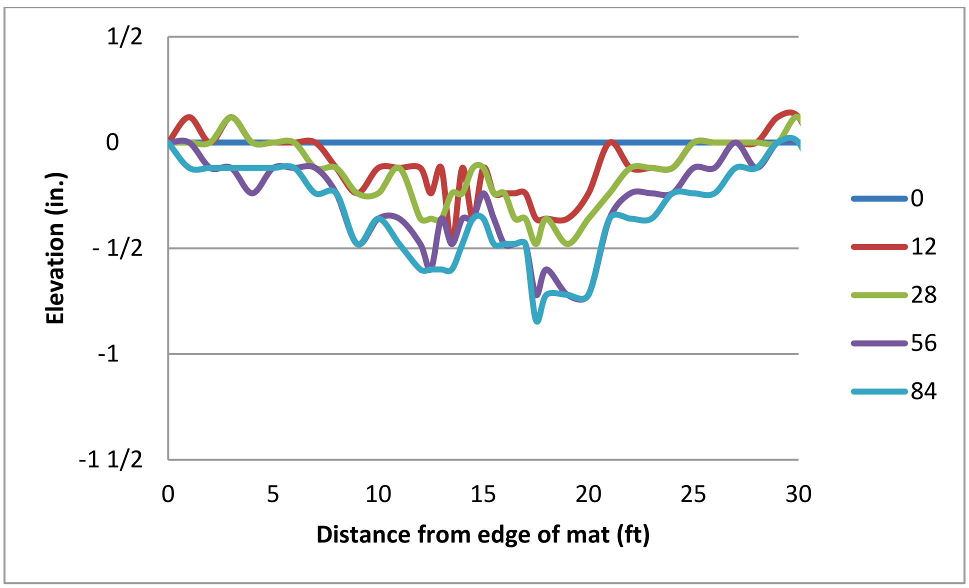


Figure 39. Elevations versus passes for C-17 on large FFM repair (mat removed).

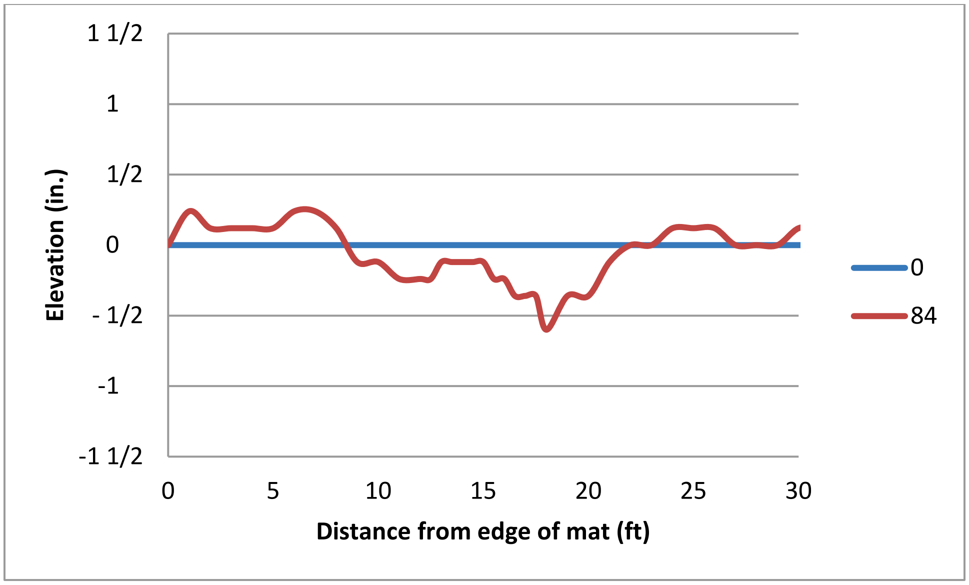


Figure 40. Elevations versus passes for F-15E on small FRP repair.

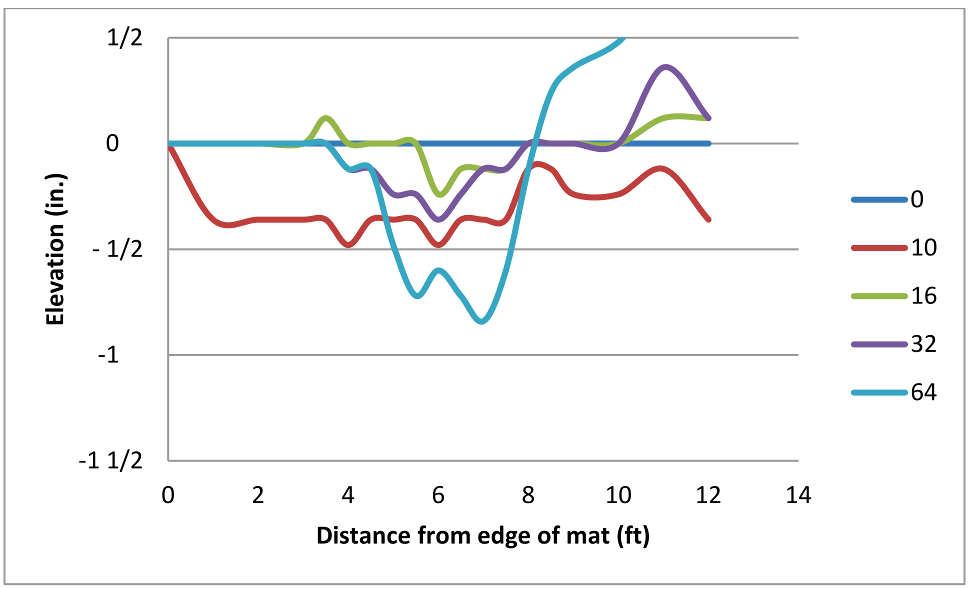


Figure 41. Elevations versus passes for F-15E on small FRP repair (mat removed).

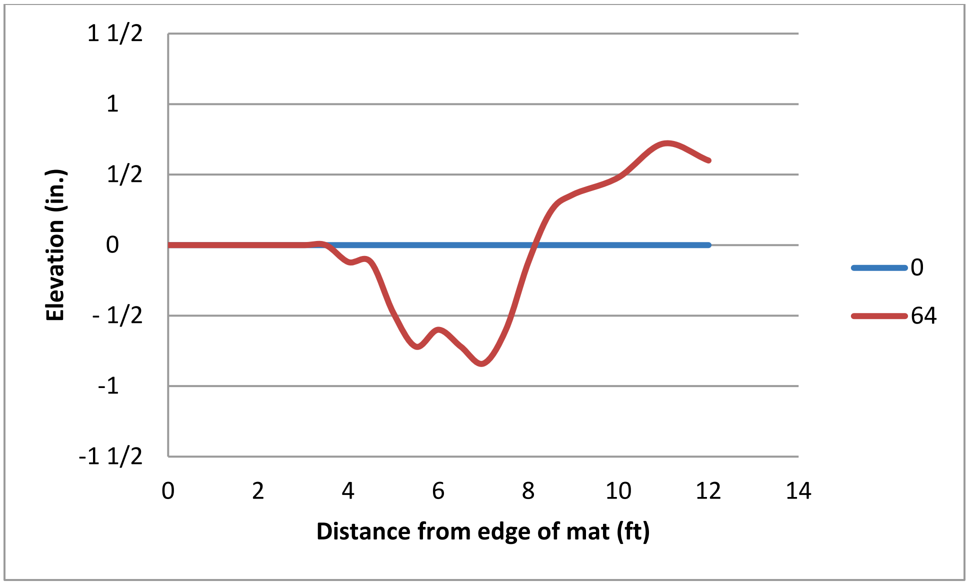


Figure 42. Elevations versus passes for C-17 on small FRP repair.

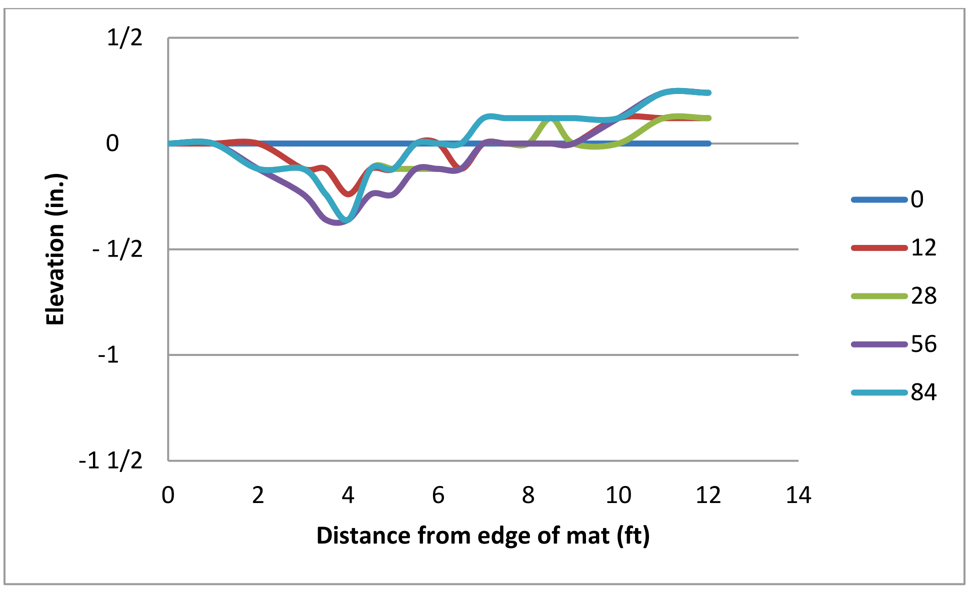


Figure 43. Elevations versus passes for C-17 on small FRP repair (mat removed).

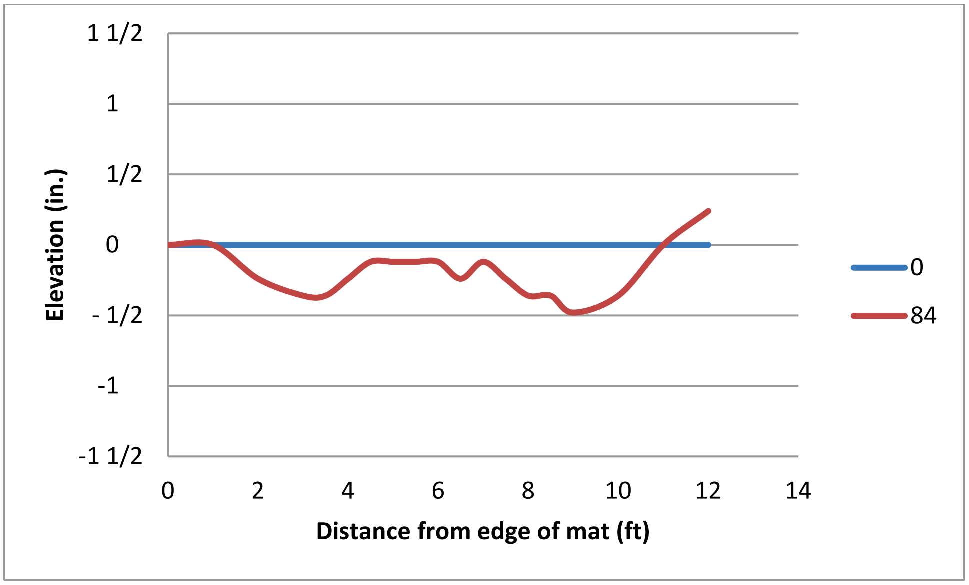


Figure 44. Elevations versus passes for F-15E on medium FRP repair.

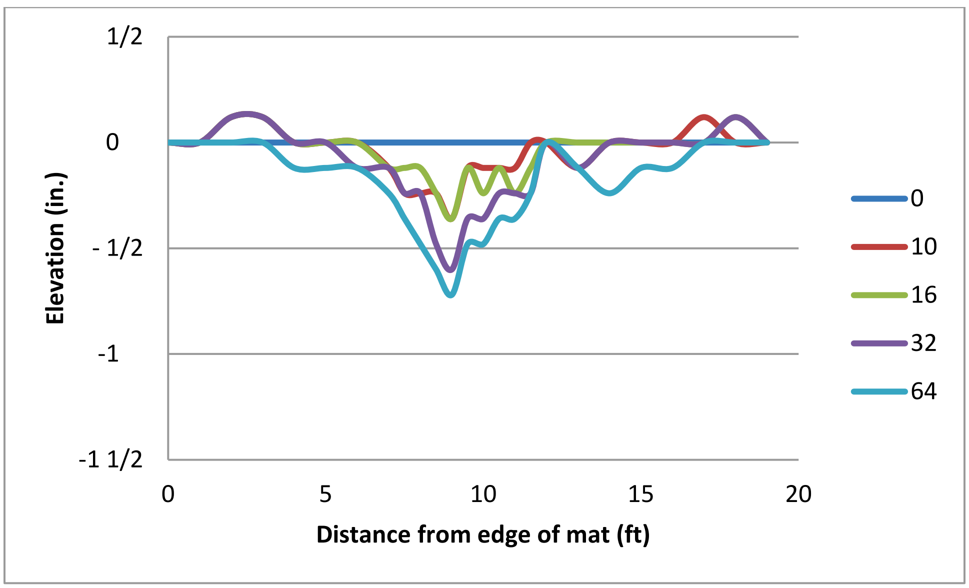


Figure 45. Elevations versus passes for F-15E on medium FRP repair (mat removed).

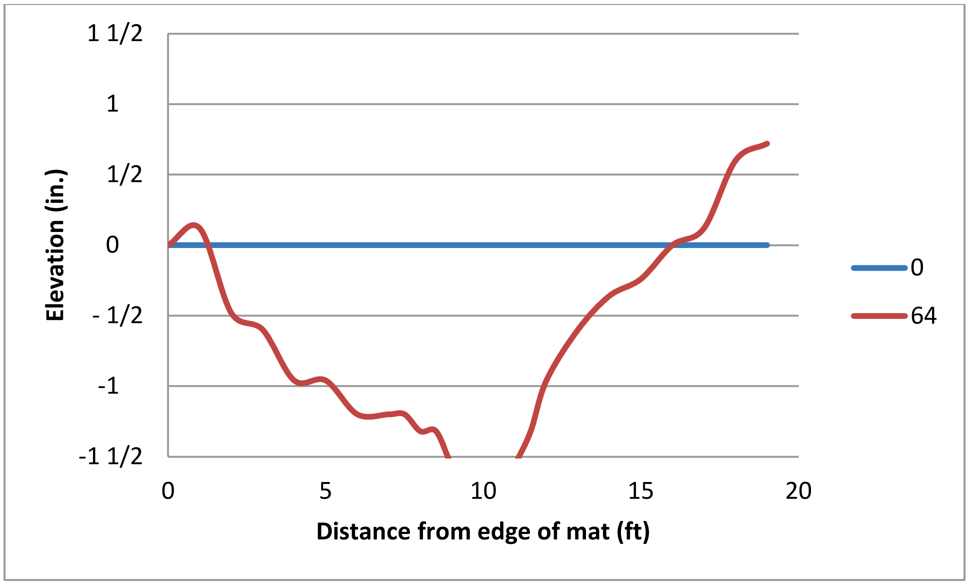


Figure 46. Elevations versus passes for C-17 on medium FRP repair.

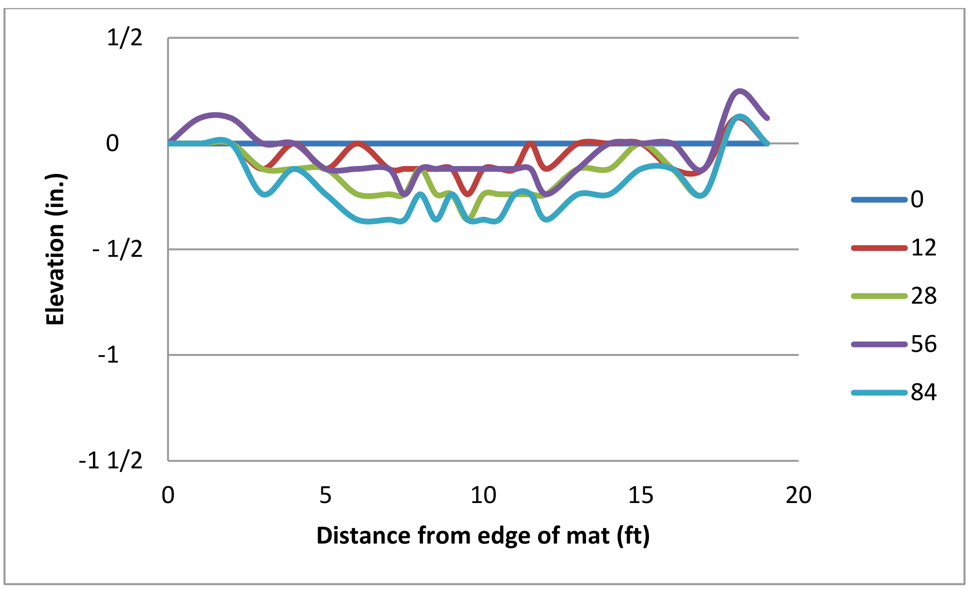


Figure 47. Elevations versus passes for C-17 on medium FRP repair (mat removed).

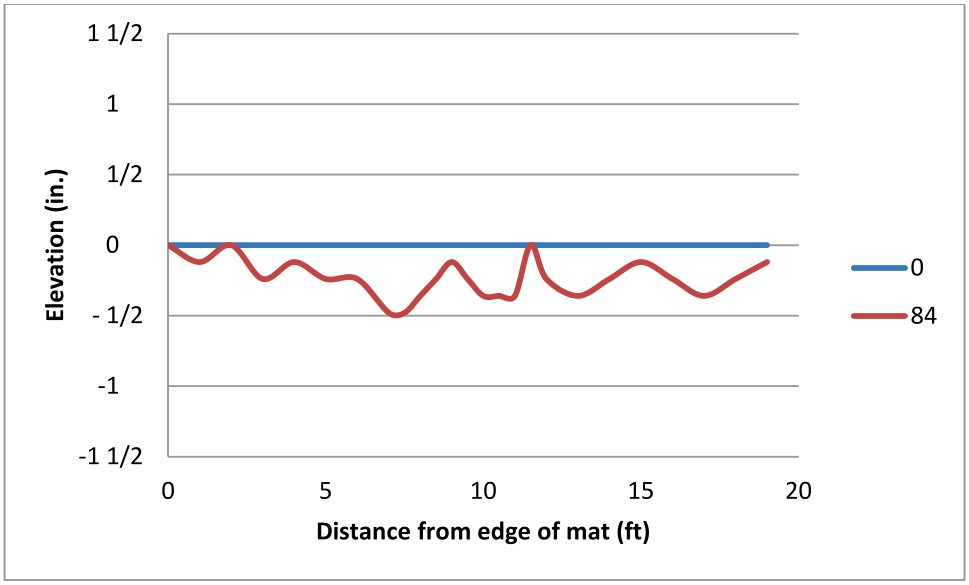


Figure 48. Elevations versus passes for F-15E on large FRP repair.

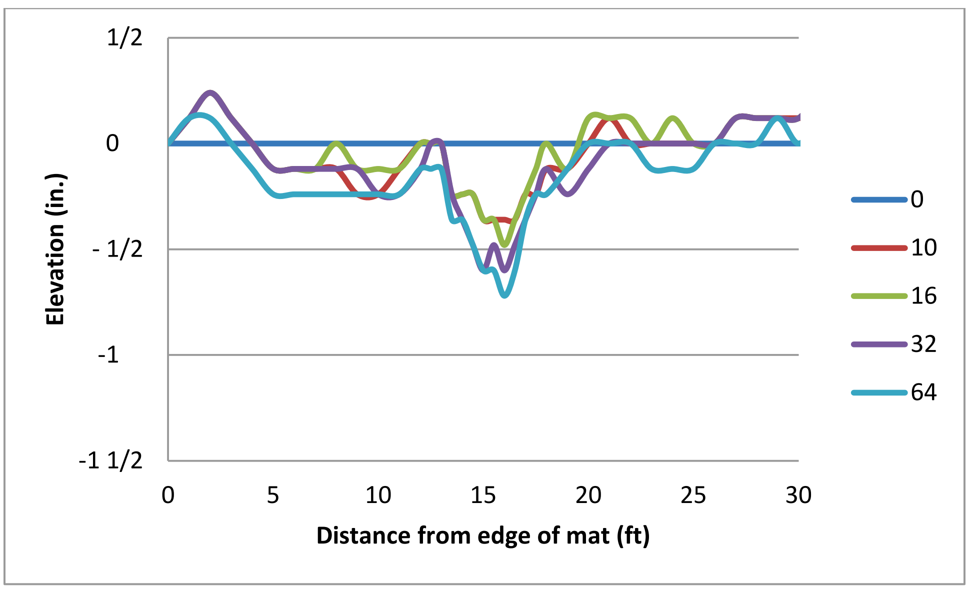


Figure 49. Elevations versus passes for F-15E on large FRP repair (mat removed).

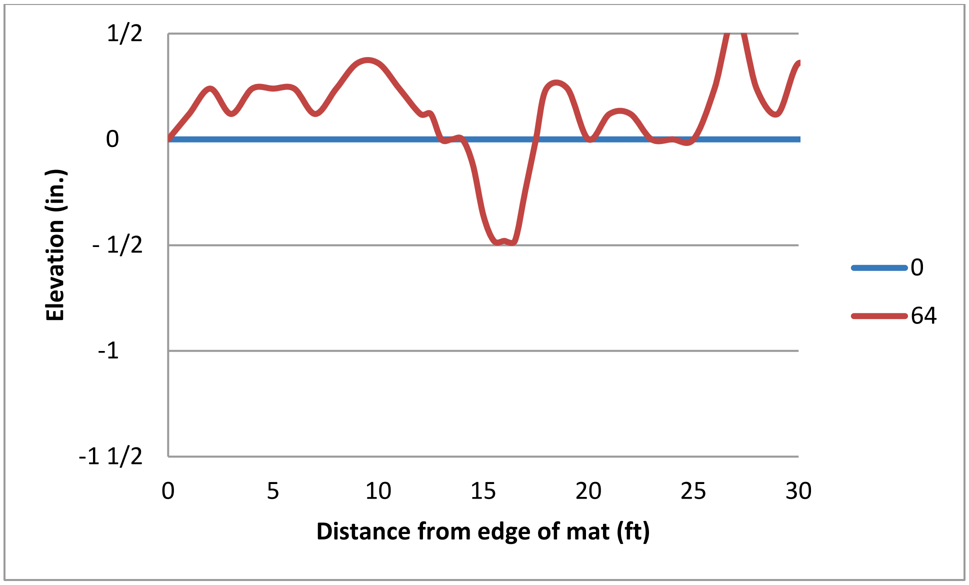


Figure 50. Elevations versus passes for C-17 on large FRP repair.

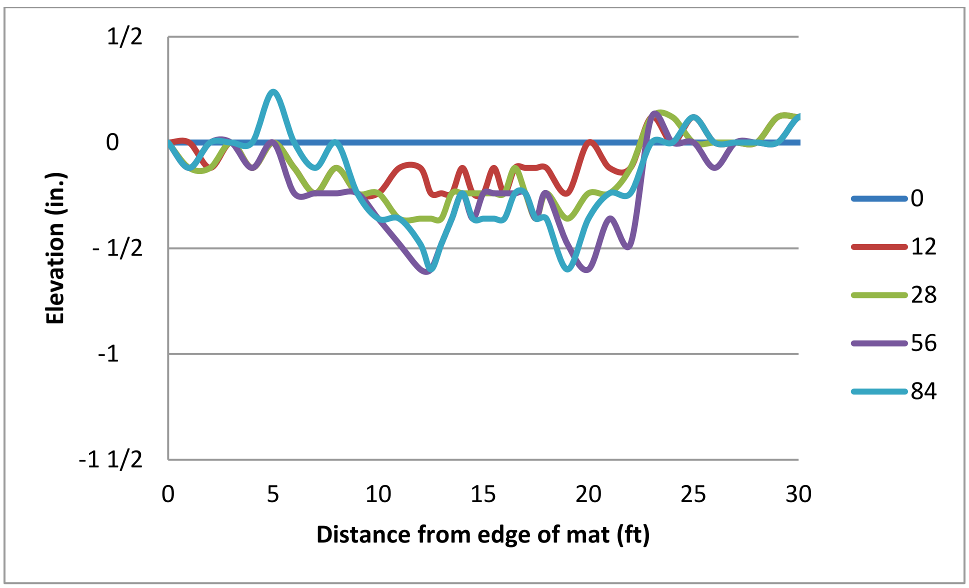
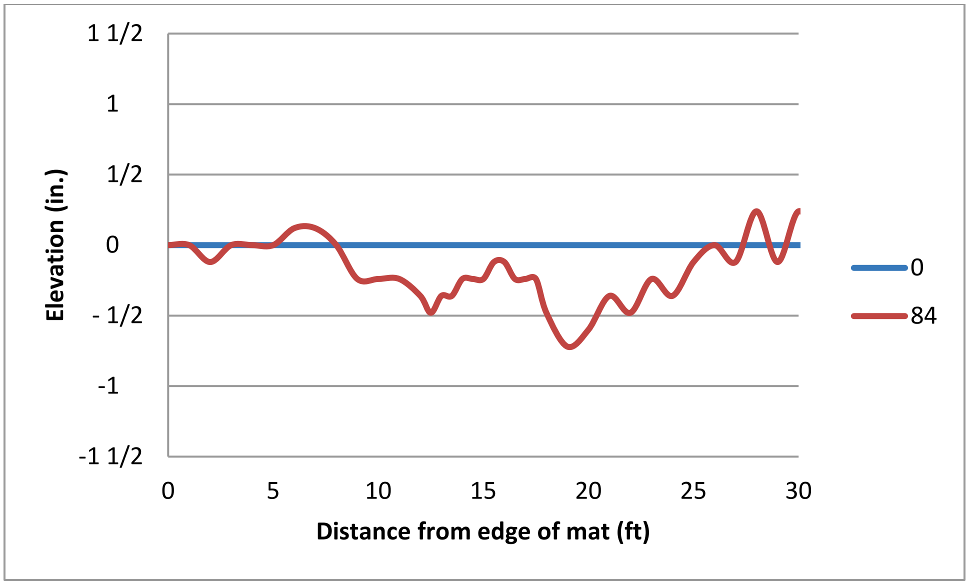


Figure 51. Elevations versus passes for C-17 on large FRP repair (mat removed).



Note that all figures show an increase in elevation across the crater repair. This increase is the natural grade of the runway. The pavement surface slopes to allow water to drain towards the edges. The elevation data during the accumulated F-15E traffic show a rut developing in every crater. In general, the total rut depth was 3/4 in. after 64 passes. The data show that the C-17 traffic caused some additional deformation, but the rutting was not as severe as it was with the F-15E.

The important result from these data is that the different FOD covers do not affect the performance of the crushed stone repair based on the limited traffic applied. Surface rutting is experienced under both FFM and FRP at approximately the same rate. The repair performance is dictated by the properties of the stone backfill and the quality of the repair.

The actual matting performance during the traffic simulations was the same for FFM as for FRP. There were no performance issues with either mat during the applied traffic. Visual inspections showed no evidence of mat damage. The application of 64 F-15E passes and 84 C-17 passes was used to validate that each mat could meet the requirement of withstanding 100 passes of mixed traffic.

6 Lessons Learned

The airmen participating in the demonstration were asked to provide feedback on the materials, equipment, and processes throughout the exercise. This chapter conveys results from the feedback provided by the airmen and results of the team's efforts during the exercise.

6.1 Crater repair

The heavy-equipment operators performing the crater repairs preferred the modernized ADR equipment set compared to the legacy equipment. A particularly liked item was the compact track loader with the multiple attachments available. Compacting the stone backfill was the greatest challenge experienced during the exercise. The large roller was too big to operate in the smaller craters. It was suggested to add a small steel wheel roller rather than use the jumping jack compactor. A steel wheel compactor skid steer attachment is provided in the new ADR equipment set. Additionally, the equipment operators requested a grader for final preparation of the stone backfill. While not available during the exercise, it was noted that a grader is provided in their traditional equipment fleet. One item suggested was a grader attachment for the skid steer.

6.2 FOD cover installation

The assembly and anchoring of the FOD covers was the major focus of this demonstration. Overall, it was noted that the airmen preferred FRP matting over FFM because it is easier to manage and there is less loose fiberglass when handling. The FRP requires only one forklift to move, while the preferred method for handling FFM requires two forklifts. The airmen liked that FRP is scalable to fit the crater size and that it can be assembled over a crater without dragging. The most negative aspect of FRP is that the full panels are very heavy. Specific suggestions provided during the demonstration are summarized below.

- The anchor panels had 2 ¼-in. holes (for anchors). These holes should be changed to 2 ½ in. so that the auger can fit through the holes.
- The tool box should include banding cutters to remove packaging.
- The tool box should include an adjustable wrench.

- The tool box should include a 4-ft T-handle wrench for installing joining bushings.
- The tool box should include belts/straps for adjusting the mat.
- The tool box should include a torque limiter that can be used with the impact wrench.
- The tool box should include ratchet straps to secure remaining mats on forklift in a scenario where a small crater was repaired and the remaining mats needed to be transported further down the airfield.
- The tool box should replace the socket ratchet extensions with shorter extensions.
- Washers should be removed from the Powers bolts prior to usage.
- The rhino lining on the bushings made it difficult for the Powers bolts to fit through the opening.
- Training should emphasize that proper torque is required for the Powers bolts.
- The tool box should include an air compressor and wand to clean out the drilled holes.
- The tool box should include two small traffic cones to aid alignment in the case where the mat is assembled adjacent to the crater.
- The tool box should include four 3-ft straps with loops 2 in. wide.
- The tool box should include two 20-ft chains with hooks.
- The tool box should include two spade shovels.
- An eight-man team is recommended as the minimum required for FRP installation.

One result of the demonstration was the determination that an eight-man team is the minimum size recommended for either matting system. To assemble FFM, at least six men are needed for unfolding the mat bundle. The two additional men serve as the forklift operator and mat chief. When installing FRP, a minimum of six men are required to transport full panels. Again, the two additional men are the forklift operator and mat chief. Replacing FFM with FRP in the ADR doctrine will not affect the allotment of manpower.

Another important result from the demonstration was identifying the time required to perform repairs using the two matting systems. Table 18 summarizes the mat assembly time and the anchor installation time for the different scenarios performed during the demonstration.

Table 18. Mat assembly and anchoring times.

Repair	Installation Time (min)		Repair Area (ft)
	Mat Assembly	Anchoring	
FFM Small Concrete Repair	7	26	54 x 30
FRP Small Concrete Repair	3	12	18 x 13
FFM Medium Concrete Repair	5	34	54 x 30
FRP Medium Concrete Repair	3	14	18 x 19
FFM Large Concrete Repair	29	38	54 x 60
FRP Large Concrete Repair	17	30	35 x 31
FFM Small Asphalt Repair	6	52	54 x 30
FRP Small Asphalt Repair	2	42	18 x 13
FRP Large Asphalt Repair	16	102	35 x 31

Data in Table 18 show that FRP can be assembled and anchored in less time than FFM for all scenarios compared. Even though small FFM repairs only require unfolding a single matting panel, the comparative craters using FRP could have the mat assembled in 2 to 3 min. The large repair using FRP was more efficient because joining the two FFM panels often requires several adjustments to obtain alignment.

For PCC repairs, the anchoring process is the same. However, the FRP was more efficient because there are fewer anchors. In some cases, the FFM would be cut to a smaller dimension when used over small craters, so there are scenarios when anchoring would require a similar amount of time. The asphalt anchors require significantly longer to install. The FRP was installed faster than FFM over a small asphalt crater because of the fewer number of anchors; the large FRP assembly over asphalt would have required longer than the large FFM over asphalt. However, it is important to note that the anchoring method for FFM on asphalt does not sufficiently suppress breaking forces and should be replaced with the Tri-Talon anchoring system.

Data from the repairs for the anchoring portion of the repair are summarized in Table 19. The number of minutes per anchor bolt for the Powers bolts ranged from 0.5 to 0.8. The individual anchor time is approximately double given the fact that two drills were simultaneously operated during the repair. Because the anchoring process relies on a rate determined by the slowest step (drilling in this case), it would be expected that small, medium, and large craters would have the same time requirements for anchoring. However, the data show faster per-bolt installation times for the smaller craters. This phenomenon is thought to be related to fatigue of the operators during large matting installations.

The Tri-Talon asphalt anchors required approximately four times as long to install compared to the Powers bolts. The longer time is a result of the multiple steps required to install the Tri-Talon. The epoxy repair method was at least twice as fast as Tri-Talons, but it is an ineffective anchoring system.

Table 19. Anchor installation time.

	Minutes Per Anchor Bolt		
Repair	Powers	Tri-Talon	Epoxy
FFM Small Concrete Repair	0.5		
FRP Small Concrete Repair	0.6		
FFM Medium Concrete Repair	0.6		
FRP Medium Concrete Repair	0.7		
FFM Large Concrete Repair	0.7		
FRP Large Concrete Repair	0.8		
FRP Small Asphalt Repair		2.1	
FRP Large Asphalt Repair		2.6	
FFM Small Asphalt Repair			1

7 Conclusions and Recommendations

7.1 Conclusions

The objective of the demonstration was to compare installation requirements for FFM and FRP matting systems. Results from the demonstration will be used to optimize procedural guidance for installing FRP matting and to refine the inventory of supplies in the supporting toolkit. Data collected during the demonstration prove that FRP can be assembled and installed over multiple repair sizes faster than FFM when using the same team size. The scalability of the FRP matting system allows for fewer anchors required to secure the mat. The reduction in the number of anchors saves time during the installation process. Even though the panels must be joined, the assembly time does not negatively affect the mission. Results from limited traffic tests show that FFM and FRP perform similarly for both F-15E and C-17 traffic in terms of resistance to permanent deformation.

7.2 Recommendations

Based on the results of this demonstration, FRP matting meets mission objectives and can be used as an FOD cover when repairing damaged pavement using the crushed stone backfill method. Lessons learned during the demonstration should be used to modify the FRP matting kit to ensure that airmen can accomplish the task as efficiently as possible. Data from this demonstration should be used to develop tactics, techniques, and procedural guidance for incorporating the FRP system into Air Force doctrine.

References

Bell, H. P., L. Edwards, W. Carruth, J. S. Tingle, and J. R. Griffin. 2013. *Wet weather crater repair testing at Silver Flag exercise site, Tyndall Air Force Base, Florida*. ERDC/GSL TR-13-42. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Carruth, W. D., L. Edwards, H. P. Bell, J. S. Tingle, J. R. Griffin, and C. A. Rutland. 2015. *Large crater repair at Silver Flag exercise site, Tyndall Air Force Base, Florida*. ERDC/GSL TR-15-27. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Gartrell, Chad A. 2007. *Investigations for airfield damage repair kit modifications and improvements*. ERDC/GSL TR-07-16. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Gartrell, Chad A. 2008. *Investigations for airfield damage repair kit modifications and improvements, phase II*. ERDC/GSL TR-08-9. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Priddy, Lucy P., Timothy W. Rushing, and Jeb S. Tingle. 2011. *Live-flight certification testing of deployable crater repair technologies*. ERDC/GSL TR-11-1. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Rushing, Timothy W., C. Floyd Webster, Lyan Garcia, and Quint S. Mason. (n.d.) *Development of an air-droppable airfield damage repair kit*. In preparation. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

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14. ABSTRACT
The U.S. Army Engineer Research and Development Center executed a field demonstration for the Air Force Civil Engineer Center to validate requirements for using Fiber Reinforced Polymer (FRP) matting as a foreign object debris cover when repairing damaged airfield pavements using crushed stone. A side-by-side comparison between FRP and folded fiberglass matting (FFM) was performed on simulated small, medium, and large craters in Portland cement concrete and asphalt concrete pavements. The demonstration took place at the Silver Flag Exercise Site at Tyndall AFB, Florida. Experienced non-commissioned officers from multiple units performed the crater repairs and matting installations. Tools, processes, and team requirements were evaluated during the demonstration. Results from the demonstration indicate that FRP matting can be installed faster than FFM, and simulated traffic tests proved that FRP can meet the minimum traffic requirements.

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Pavements, Asphalt concrete – Testing
Portland cement
Landing mats
Cratering